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PROCEEDINGS

Workshop on
Materials Handling for Tunnel Construction
Keystone, Colorado August 3-5, 1977

Robert R. Faddick and James W. Martin, Editors

OCTOBER, 1977

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16. Abstract

With the anticipated increases in tunnel construction in the next decade, greater demands will be made on transportation systems to remove tunnel muck at rates consistent with tunnel excavation rates. Conventional materials-handling systems such as rail, rubber-tire vehicles, and conveyors will have to expand their capabilities. Simultaneously, hybrid and lesser known systems such as pneumatic and slurry pipelines must be considered as potential systems for muck haulage, particularly since they show substantial promise of being capable of transporting the muck volumes projected for the next decade.

A workshop entitled, "Materials Handling for Tunnel Construction", was held August 3, 4, 5, 1977 at Keystone, Colorado. Experts were invited from the construction, metal and non-metal mining industries. The participants evaluated the state of the art of materials-handling systems for underground construction, exchanged information on current systems applications and research, itemized research needs, and produced a written summary of their conclusions.

This report comprises the proceedings of the workshop.

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Acknowledgements

A workshop becomes successful only when the first four letters of "workshop" are stressed. Such was the case for the Keystone workshop, thanks to the following people:

Bruce Bosserman, Technical Project Monitor, DOT-TSC

Gilbert Butler, DOT-UMTA

Doug Johnson and Ed Norman, UCRC Co-ordinators

Roger Dewey, workshop manager

Special thanks go to Joe Sperry who planted the seed of the workshop idea and nurtured it to harvest time.

INTRODUCTION AND PURPOSE

INTRODUCTION

The Materials Handling Task Committee of the Underground Construction Research Council of the American Society of Civil Engineers has enumerated materials handling systems where it is felt improvement is required. Some of these are:

1. Develop a continuous method of removal up vertical shafts.
2. Improve rail haulage systems to increase reliability and speeds.
3. Expand research and development efforts in the loading of blasted muck.
4. Metallurgical improvements designed to increase the reliability and life of all materials handling systems.
5. Improve conveyor systems for greater reliability and extensibility.
6. Develop pipeline systems to transport muck economically.

An intensive workshop was proposed as a timely approach to stimulating more in-depth consideration of the above problem areas and provide the essential communication link between industry, government and research.

PURPOSE OF THE WORKSHOP

The intent was to establish a true workshop where infor-

mation and work assignments were submitted in advance to attendees with the goal of producing a definitive document at the close.

The workshop brought together for several days invited experts on various materials handling systems for underground construction. They heard three keynote speakers who evaluated the state of the art of materials handling systems in underground construction, metal mining and non-metal (coal) mining. Seven more experts in particular materials handling systems also participated.

Emphasis was placed on evaluating the state of the art with respect to equipment and techniques, current research and applications. Muck preparation and disposal were included where applicable. Thus on a short-term basis, an information exchange and up-dating was effected. On a long-term basis, research needs were identified to improve system capabilities and reliability and reduce costs of materials-handling systems for tunnel construction.

It was felt that major advancements in the field of materials handling for rapid transit tunnel excavation would be implimented best by adapting ideas and techniques now used in general underground construction, metal mining, and coal mining.

WELCOMING REMARKS

Gilbert Butler, P.E.
Program Manager
UMTA Tunneling Technology R&D Program
Washington, D.C.

WELCOMING REMARKS
by
GILBERT BUTLER

Good morning and welcome to this workshop on behalf of the Urban Mass Transportation Administration (UMTA) and our newly appointed and confirmed Adminstrator, Richard Page.

I am the program manager of the UMTA tunneling technology R&D program. This workshop is conducted as part of a coordinated U.S. Department of Transportation tunneling program which we have been talking about, promoting and discussing all across the country. This departmental program also includes the Office of the Secretary of Transportation and the Federal Highway Administration. Within UMTA, the tunneling program is carried out under the Assocate Administrator of Technology Development and Deployment.

I am particularly pleased to participate in this workshop as sponsor because it is this type of activity that will provide the industry and the Federal Government with an identification of both near and long-term technical problems and the potential for resolving those problems through R&D. Through the UMTA tunneling program, we have sponsored four seminars on topics such as precast concrete tunnel liners in Baltimore, underground construction problems in Chicago, site exploration and construction monitoring in Boston

and Atlanta, and we plan to continue to sponsor additional workshops such as this one.

One of the many good reasons we are happy to sponsor these seminars and workshops is the benefits of the interaction between the Federal government, industry and academia. Every year my boss has to walk up to the "Hill" and argue, beg, and defend money for R&D and every year the first standard question from the committee is "Well, young man, we gave you $368 million over the past six years, what can you show for it?" We believe we have quite a bit to show for it from all the many various programs, but nevertheless it is very obvious to us that the only way we can show something for all that money is to work very closely, hand-in-hand, with the people who are doing the things whether it is materials handling, transit vehicle development or whatever, in urban mass transportation.

In other words, it's obvious that the only way that results of R&D can be measured and appreciated by the public is by seeing what's out there that either works better or, let's face it, costs less, and preferably, both. It is this kind of thinking that has caused us to do a modest shift in our programming and in our philosophy to move more and more towards the cooperative activities of trying out, testing and evaluating things that we believe, based on R&D, either domestically or abroad, that appear to offer promising results. This whole idea of what we call the delivery

system for putting R&D results into practice is reflected in the UMTA Associate Administrator's title of Technology Development and Deployment rather than Research and Development. We are looking for the best way and best opportunity to participate, to assist, and to make things happen and by doing it, perhaps share the risks as well as stimulate occasionally the taking of risks where the payoffs appear to be well worthwhile.

Some of you might be somewhat confused by the numerous organizations involved in putting this workshop together. The Urban Mass Transportation Administration in spite of what the media like to present about Federal bureaucracies, is not an overgrown agency. On the contrary, UMTA is a deeply undermanned bureaucracy with a work force of about 450 people compared to 55,000 in the FAA. Because of our tremendous people limitations we are very happy to use the resources of the Transportation Systems Center (TSC) in Cambridge, Massachusetts which is a U.S. Department of Transportation facility in terms of people, competence, technological ability, as well as procurement, to help us carry out some of the UMTA programs. So we in effect use the Transportation Systems Center as a prime contractor to procure services of R&D contracts for us. In this case, TSC contracted with the Colorado School of Mines to put together this workshop. TSC also contracted with Ahmed Associates

to provide the administrative support activities for this and other workshops. And as you know, the Colorado School of Mines was assisted by the UCRC Materials Handling Task Committee of ASCE, AIME. I would say that we have certainly satisfied our goal of hand-in-hand cooperation with the people who are making things happen.

Once again, welcome to Keystone and we are indeed looking forward to the results of the effort you will be putting forth during the next few days. Thank you.

PAPER 1

Materials Handling Research Being Conducted by the U.S. Department of Transportation

Bruce Bosserman, C.E.
U.S. DOT Transportation Systems Center
Cambridge, MA

"MATERIALS HANDLING RESEARCH BEING CONDUCTED BY THE U.S. DEPARTMENT OF TRANSPORTATION"

Bruce Bosserman

At present, the U.S. Department of Transportation (DOT) is funding four research contracts dealing with materials handling in tunneling. Following is a brief summary of each research effort.

Testing Program for the Experimental Verification of a Pneumatic Muck Transport System

Contractor: Colorado School of Mines
Principal Investigators: Dr. Robert R. Faddick
Prof. James W. Martin

The objective of this contract is to test the reliability, wear and maintenance requirements, capacity, noise and dust levels, energy requirements, and costs of both a muck preparation unit and a pneumatic conveyance system. Based on conclusions of a 1974 DOT study entitled, "Pneumatic-Hydraulic Materials Transport Systems for the Rapid Excavation of Tunnels", a pneumatic pipeline system was purchased and installed for testing. The system consists of:

- A muck preparation unit (screens, impactor and conveyor belts), skid mounted
- A blower, skid mounted
- Two telescoping pipe sections to provide 30 feet extensibility, skid mounted
- 500 feet of 10 inch diameter hardened steel pipe for horizontal and vertical lift

Tests were performed to evaluate the following system parameters:

- Wear (in pipeline, crusher and feeder)
- Pipeline extensibility to simulate operation behind a tunnel boring machine
- Effect of particle type, size and moisture content on system performance
- System energy requirements
- Tonnage rates achievable through the system

Testing will be completed in August 1977, with a final report available at the end of 1977.

Tests have shown that the pneumatic system has great potential for muck handling in tunneling, especially for vertical transport. The next phase of the program will be to install the pneumatic equipment in a tunneling situation.

The Transportation of Tunnel Muck by Pipeline

Contractor: Colorado School of Mines
Principal Investigators: Dr. Robert R. Faddick
Prof. James W. Martin

The objective of this contract is to advance the state of pipeline muck haulage systems through analysis of crushing equipment, extensible conveyors, hydraulic slurry head loss data, and slurry dewatering systems.

The study has been completed and the report, to be available in late 1977, will provide detailed analysis of:

- Muck quantities and muck quality (in terms of its hardness and geology) which can be expected in future tunneling operations.
- Crushing equipment to provide desired particle size distribution for input into pipeline systems.
- Extensible conveyor equipment to aid in suggesting approaches for their application in tunnels to pipeline muck haulage.
- Recent head loss data for coarse slurries as applied to hydraulic muck haulage systems.
- Jet pump educators for feeding a centrifugal pump from a mixing tank.
- A more compact and less expensive dewatering system.

Materials Handling Systems Study

Contractor: Holmes and Narver, Inc.
Principal Investigator: James M. Duncan

The objective of this contract is to assess the potential for achieving construction cost economies in tunnel construction through selection of more efficient materials handling systems and/or further development of system components.

The study is divided into three major areas:

- Survey of the state-of-the-art of materials handling in tunneling and of materials handling systems which might be applicable to tunnel construction.
- Development of a cost estimating model and determination of comparable costs for various materials handling systems.

- Recommendation of a Research and Development (R&D) Program for materials handling based on benefit/cost evaluation of potential R&D projects.

To date, materials handling problems have been discussed with 15 engineer/manufacturers, 16 tunnel contractor groups, 4 mining operations and 10 other organizations (schools, agencies and individuals) to determine the state-of-the-art and future research needs. The cost estimating model which has been developed forthe study is based on a professional construction cost estimator's standard methods for estimating construction tenders for tunnel bid solicitations. The estimation procedure has been computerized to reduce the time required for consideration of alternative materials handling systems and components.

The study is approximately 50% complete. The final report will be available in mid 1978.

Hydraulic Transportation and Solids Separation of Excavated Materials in Tunnels

Contractor: University of Minnesota
Principal Investigators: Prof. Charles Nelson
Prof. Donald Yardley

The objective of this contract is to increase the use of hydraulic transportation of tunnel muck by documenting a system which is now in use and by developing solids-water separation methods which will make the system compatible with the urban environment.

Hydraulic transportation of tunnel muck can be safe and economical; however, it is not in wide use except in the Twin Cities area in Minnesota. There it was developed along with hydraulic cutting for tunneling in the week St. Peter sandstone. Most of the system used in the St. Peter sandstone could be used in soils and various soft rocks in other areas.

This research program was initiated to:

- Document performance and costs of current hydraulic tunneling and materials handling projects in the Twin Cities area.
- Document muck volume and solids content on a hydraulic mining tunnel construction project.
- Study muck characteristic pertinent to solids-water separation operations.
- Perform laboratory and pilot plant tests on actual tunnel muck.
- Design prototype optimized muck treatment system.
- Monitor operations of the prototype system at a hydraulic mining tunnel construction project.

Presently monitoring of a completely closed loop system is being completed. This system shows great potential for reducing environmental impact of hydraulic tunneling projects. The report will be available in early 1978.

To conclude, I would like to emphasize how valuable the results of this workshop will be to the DOT tunneling program. The recommendations of this groups of materials handling experts from mining and tunnel construction, combined with the work of Holmes and Narver, Inc., will establish the areas where DOT needs to conduct tunneling research to provide maximum benefit to the tunnel construction industry.

PAPER 2

Underground Coal Mining with Particular Reference to Transportation Methods in Use

J. W. Wilson
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Houston, TX

UNDERGROUND COAL MINING WITH PARTICULAR REFERENCE TO TRANSPORTATION METHODS IN USE

J. W. Wilson

INTRODUCTION

Coal reserves represent 90% of the domestic source of energy for the United States. However, coal currently provides only 18% of the energy consumed in the Nation. The growing shortage of oil and natural gas, coupled with the rising consumption of energy, has created the need to increase greatly the production of coal today and during future years.

Only after the Oil Embargo in 1973 was the vulnerability of the country's energy position fully realized, and this has resulted in a concerted effort by coal operators to expand coal production.

In a recent energy plan proposed by the President, there is a call to increase the annual coal production to over one billion tons by 1985, that is an increase of 400 million tons per year over the present annual tonnage. Coal industry leaders suggest that a more realistic expansion of coal production is about 600 million additional tons by 1985, since plans are already in progress to bring on 400 million tons for additional electric power generation. Both these proposals indicate a tremendous expansion program for the coal mining industry.

Today, just more than 50% of the coal mined in the United States comes from surface mines and the large untapped reserves of strippable coal in the West suggests that there are excellent opportunities to meet the above expansion by increasing surface mining considerably. However, governmental constraints centered around Federal Leasing of Western coal and proposed surface mining reclamation requirements are expected to restrict the growth of strip mining coal production. This, in turn, will result in substantial growth in underground coal production to meet the overall coal output targets.

The need for increased coal production from underground mines has come at a time when the productivity of these mines has dropped from a high of 15.6 tons per manday in 1969 to 8.5 tons per manday in 1976. This decline in productivity has resulted from a number of causes, the most significant of which has been the introduction of the new coal mine Health and Safety Act in 1969. Attempts to reverse this productivity decline has been in the development of new technology and mining equipment. Coal mining machinery has been designed to increase the mining rates so that the output from the available time during a shift can be improved. Over the last eight years it has become apparent that even the more powerful, faster cutting rate machines have not been able to arrest the productivity decline in the traditional room-and-pillar mining sections. However, there is encouragement in the improvements in productivity that has resulted in some underground mines where Longwall and Shortwall mining methods have been introduced. Should these mining methods become adaptable to more underground mines, it is probable that there will be greater demands on the current mine transportation systems in use.

Underground coal mines in the U.S.A. vary in size from as small as less than 50,000 tons per year to as large as 4 million tons per year. During 1976, ten of the highest coal producing mines were underground mines, but typically underground mines range from 250,000 to 1.5 million tons per year. With such a wide variety of production levels, mining equipment used for mining and transportation varies considerably.

The primary function of underground transportation is to move coal from the mining area to the surface. This function is served by the equally important support services of supplies handling and personal conveyance. The equipment and applications of this equipment are as varied as the seams that are encountered in United States coal mining,

for example, variations in thickness, in pitch and in roof and floor conditions.

It is these physical conditions that ultimately dictate the plan of coal recovery, which in turn bear directly on equipment selection. To ensure that haulage facilities of equal or greater capacity are developed to match the capacities of modern mining machines, operators, Research and Development organizations and manufacturers are devoting increasing attention to the area of coal, supplies and personnel transportation in mines.

To indicate why the various transportation systems are used in underground coal mines, a review follows of the common mining methods currently in use in the United States.

UNDERGROUND MINING METHODS

There are basically three different types of underground mines that can be identified by the type of opening from the surface to the coal seam.

A Drift Mine is one in which a horizontal, or nearly horizontal seam of coal outcrops to the surface in the side of a hill or mountain, so that the opening into the mine may be made directly into the coal seam. This type of mine is generally the easiest and cheapest to open because no rock excavation work is required. Transportation of coal to the outside may be track haulage, belt conveyor or battery powered rubber-tired equipment.

A Slope Mine is one in which an inclined opening is used to gain access to the coal seam(s). A slope may follow the coal seam if the coal seam itself is inclined and outcrops, or the slope may be driven through rock strata overlying the coal to reach a seam. Transportation of coal from a slope mine can be made by conveyor or by track haulage, using a trolley locomotive if the grade is acceptable, or by pulling mine cars up the slope using an electric hoist and steel rope, if the grade is steep. The most common practice is to use a belt conveyor where grades are kept below 17^{o}.

A Shaft Mine is one in which the coal seam is reached by a vertical opening from the surface to the coal seam(s). In general, shafts are preferred to slopes for bringing coal out of the mine if the coal seam lies under a cover of more than, say 500 ft. Figure 1 illustrates the three shaft types described above.

Sometimes an individual mine will have all three types of openings, i.e., Drift, Slope and Shaft. For example, the coal haulage might come to the outside through a Drift opening if the cleaning plant is close to the outcrop. As the mine develops under deeper cover, additional openings become necessary for ventilation and for portals to shorten the travelling time for men and supplies. A slope might be used for the Portal where the overburden is not too great and a vertical shaft or shafts may be used for air. Where the cover exceeds, say 500 ft., it is generally more economical to use shafts for men, supplies and equipment.

Underground mining systems used for coal production can be broadly classified into Room and Pillar, Longwall, and Shortwall Methods.

UNDERGROUND MINING METHODS

ROOM-AND-PILLAR MINING

Historically, virtually all U. S. Underground coal mining has been done by the Room-and-Pillar Method which today includes both Continuous and Conventional mining equipment. The Room-and-Pillar Method involves removing coal by means of cutting a series of entries or rooms of small size into the coal seam. About 50% of the coal is left either temporarily or permanently in the form of pillars adjacent to the rooms. The pillars hold the overall roof up. The roof is supported locally between the pillars by installing supplementary bolts into the roof, erecting posts, timbers etc. The extraction ratio varies, depending on the depth of the coal seam, nature of the roof and floor, strength of the coal itself, and other factors. In areas where subsidence of the surface can be allowed, the pillars of coal are sometimes partially removed as the final step in mining in a given location in a mine. The degree to which the pillars are removed is a function of local conditions and economics, and it varies widely.

In general, the Room-and-Pillar Method is a flexible system that can accommodate varying mining conditions, including working around zones of faulting, old oil and gas wells, and local areas of bad floor or roof.

Room-and-Pillar mining operations can best be described by discussing three functions performed within a working section. The first function is the cutting of the coal by either Continuous or Conventional mining equipment. The second function performed is the haulage of coal and rock away from the face. The third function includes services and all other section activity necessary to the mining of coal.

CONTINUOUS MINING MACHINERY

Continuous mining machines remove coal from the seam, fragments it, and loads the coal onto haulage equipment in one continuous operation. The instantaneous rate of coal removal varies from 8 to 10 tons per minute. These machines are categorized according to the mechanical configuration of coal-fragmenting apparatus. There are four basic types of Continuous Miners, namely, Drum, Ripper, Borer, and Auger.

The Drum Continuous Miner is the most widely accepted machine and is also called the Milling-type Miner (Figure 2). Bit wheels are rotated parallel to the face and break the coal. The Drum Miner is available in a full-face or a two-step model. The full-face model will normally cut a path 14 to 17 feet wide providing clearance for the operator and machine as it mines. The Two-step Continuous Miner normally cuts 8 to 12 feet wide as it advances and requires at least two passes to advance an entry. The normal procedure is to make the first pass, or box cut, 8 to 10 ft. deep, back out the Continuous Miner and make the slab cut or second pass 8 to 10 feet beyond the first box cut. The machine is then backed out and the face of the first pass advanced to the final position of the second pass to square up the face. The mining machine normally takes coal by sumping into the coal 14 to 18 inches, then shearing down to the floor, and backing up when the floor is reached to trim off the ridge of coal left by the cylindrical drum.

Ripper-type Continuous Miners use several chains in a rectangular array to saw against the face (Figure 3). These machines are mounted on crawler treads and usually cut a place 14 to 18 feet wide with cutting heads 3 1/2 to 4 feet wide. The cutting cycle begins with the cutting head retracted. This cycle is repeated four or five times alongside the first cut until the full face is mined 14 to 24 inches deep, at which time the Continuous miner is trammed to the face again. Because this type of machine is narrow for the width it cuts, it is very maneuverable.

The Borer-type Continuous Miners are true full-face machines and have an arm (or arms) that rotate against a flat face and produce an arched entry (Figure 4). This machine cuts the full height and width in one operation, tramming slowly forward all the time. A drawback of this Continuous miner is that it is very large for the entry it cuts, leaving barely enough room for the operator. The arched roof contour is good for roof control but restrictive in entry width, which in turn affects the ventilation and seriously impedes the mining of seams with variations in thickness.

A category of Continuous Miner designed primarily for low coal (25 to 27") is the Auger, which can cut coal up to 48 inches thick (Figure 5). These machines are skid-mounted and pulled through their cycle, and all tramming is performed by cables attached to winches mounted on the Auger Miner. There are four sheaves, or pulleys, on the machine, two at the front and two at the rear. When the Auger is cutting into the coal, the cables pass around the rear sheaves to roof jacks near the face, then the cables are winched in, pulling the Continuous Miner into the coal approximately four feet. After this cycle, one of the cables is loosened and pressed over a front sheave, anchored on a jack on one side of the entry, and the cable again winches in, causing the Auger to shear across the face in the opposite direction. One of the major advantages of this type of machine is that its system is compatible with, and often used in conjunction with, continuous haulage.

Although the Continuous Miner cycle consists of one continuous operation performed by one machine, the Conventional mining cycle consists of four distinct operations performed by three separate machines.

The Conventional mining cycle consists of undercutting, drilling/shooting (blasting), and loading the coal. Usually, all of these operations are fairly well balanced so that equipment is operating most of the time in each "place" (Figure 6). Maximum production is, of course, limited by the slowest operation. The key to good loading is good preparation (cutting, drilling, and shooting). Cutting of the coal face is accomplished by a machine that makes a horizontal groove in the coal face 8 to 10 inches in thickness across the full width of the face and 8 to 11 feet deep (Figure 7). This creates an additional free face to which the coal to be blasted can be broken. Drilling is performed by a machine utilizing small diameter augers to drill small holes in a set pattern in the coal face to the approximate depth of the horizontal groove made in cutting (Figure 8). The material undercut and drilled is termed a "cut of coal" and may typically contain 20 to 50 tons. Shooting in the cycle is performed by charging the holes with permissible explosives or specially designed compressed-air cylinders and blasting to break down the cut of coal. The shot material is then gathered up by a loading machine (Figure 9).

RETREAT MINING OR PILLAR EXTRACTION

Where Retreat Mining or pillaring is practiced to maximize coal recovery using Continuous or Conventional equipment, the law specifies that an approved roof control plan must be used; that during development the size and shape of the pillars should be dictated by geological factors and never smaller than 20 feet. Before pillaring is started, a minimum of two rows of breaker posts or the equivalent must be installed not more than 4 foot apart across each entry leading into the area to be pillared. A special roof control plan must be adopted when supports are installed intermittently or when equipment is designed to provide either natural or artificial support as the coal is mined, e.g., the Continuous mining machines that cut arched roofs.

Two things must be considered to understand Pillar Extraction operations. One is the sequence of removing pillars and the other is the sequence of steps taken to remove each pillar. The same approach to the removal of individual pillars is used for Continuous and Conventional equipment, the only difference being that the Conventional method requires four to five times as much time to remove a pillar as does the Continuous method. In most mines where pillar extraction is practised, the pillars are usually square in shape. A square pillar provides the choice of which side to begin mining, which in turn, provides flexibility sometimes needed under difficult geological conditions. Retreat mining is similar to normal advance work, but care must be taken to remove enough coal so that the roof caves after pillaring. If the local roof does not collapse, its weight is carried by the remaining pillars, and if enough weight is thus transferred, an unsafe condition will exist. Three methods of pillar removal are common and are termed: Open End, Pocket and Wing, and Splitting. When using the Open-End Method, each lift or slice of coal is mined from one side completely through to the caved roof, (the previously pillared area). Individual cuts can be of varying widths but each one is on an open end and goes to the caved area (Figure 10a). The Pocket and Wing Method implies that after each cut a wing (or fender) of coal is left between the cut and the caved area. These wings are also mined in pieces after each cut (Figure 10b). Splitting refers to the practice of cutting through the center of the pillar leaving two large wings (Figure 10c). These wings are then mined, or if bottom and roof conditions require it, are left to temporarily support the roof during pillaring operations.

COAL HAULAGE

By far the most common face-haulage system used in room-and-pillar mining consists of shuttle cars. (Figure 11). These vehicles transport the coal from the Continuous miner or loader to the intermediate or main haulage loading point, from which the coal is transported to the surface.

Face haulage is primarily of two types - wheeled intermittent units and continuous transport types. The former can be further classified with regard to power source and dumping mechanism. Intermittent haulage types are the cable reel shuttle car, and several types of non-cable cars such as: the battery ram-dump car, the battery tractor-trailer unit, the "scoop" or front-end loader, and the diesel ram-dump type of car.

Continuous haulage types that have been introduced into room-and pillar mining include chain or belt conveyors, extensible belts, bridge carrier systems, and modular interconnected conveyors. Some of the latest attempts to achieve continuous haulage from a continuous miner include new designs of bridge carriers, modular extensible belts, serpentine belt systems and monorail suspended belts. Hydraulic transportation with flexible hoses and pneumatic transportation have also been studied.

A more detailed discussion on haulage systems follows later in this paper.

SERVICES AND SUPPORT ACTIVITY

Roof support is a major activity in underground mines, especially those mines with known bad roofs. By law, mine operators must have an approved roof support plan and update that plan every six months. Bolting is the technique of supporting the roof with long bolts placed in the roof which bind the layers of roof material together, providing structural integrity.

The current mining law covering roof support has a direct effect on section operations and production levels. In general, temporary support must be installed first and only the men who install the supports may work under the temporary supports until permanent supports are in place. The continuous miner operator cannot operate the machine unless he is under supported roof. Spacing of roof bolts in a roof bolting plan is limited to no more than five feet from either of the coal ribs, the face, or each other. Entry widths are limited to twenty feet and 25% of the bolts from the outby corner of the last open crosscut to the face, being checked on a daily basis.

Mines must be ventilated to provide air for the workers to breathe, and to remove dangerous gases such as methane and carbon monoxide, as well as explosive coal dust. Cross ventilation is normally accomplished with one or more fans, usually of the exhaust type. The flow of air throughout a mine is directed by cinderblock stoppings, regulators, check curtains, line brattice, doors, and overcasts.

Ventilation planning has a direct effect on section operation and layout. Ventilation requirements that must be met include: a maximum of two crosscuts must be left open to separate the intake and return air paths; each mechanized section must be ventilated by a separate split of air; 9,000 cfm of air must be passing in the last open cross cut; 3,000 cfm of air must be present within ten feet of the face; 60 fpm is the minimum velocity of air at an active face; an examination for methane must be made every 20 minutes; and methane monitors must be installed on all face equipment.

In addition to the above criteria, special air courses, known as bleeder entries, must be developed and maintained to continuously ventilate the gob or collapsed area after coal pillars are removed. The air-methane mixture from the old workings must be directed away from active workings and to the return airways.

Two other activities related to the control of coal dust and flammable loose coal, are rock dusting and cleanup. All areas within forty feet of the face and all crosscuts that are less than forty feet from a working face must be rockdusted to ensure appropriate levels of incombustible material, except those areas already too wet or too high in incombustibles to propagate an explosion. The coating of the mining area with limestone dust must be done by the end of each shift, or in the case of crosscuts, immediately after cutting. Rockdusting is done both by hand and by machine. It is also necessary to control loose coal in a working section, thus a regular cleanup and removal program must be instituted.

LONGWALL MINING METHOD

Longwall mining consists of driving one or more entries or gates, approximately 300-600 ft. apart, mining an interconnection, then mining the rib of the interconnection as the longwall face. The retreat system is used almost exclusively in the United States. Since the entries do not have to be maintained for travel inby of the longwall face, this simplifies entry support and section ventilation (Figure 12).

The reason for adopting longwall mining generations ago in Europe were generally technical, i.e., greater depth, thinner seams, limited reserves, etc., while in this country they are generally economic reasons. Longwall possesses the technical advantages of productivity unaffected by increasing depth, nearly total extraction of the coal in a panel, the ability to mine superimposed seams without one seam disturbing the other, and better surface subsidence control than with room-and-pillar mining. In addition, longwall, with its continuous steel supports, is inherently safer. The

supply of materials, ventilation, and power to a longwall is simpler because the working area is concentrated along a single face. Since additional supports are not used and rock dusting is not required, these costs are minimized. The potential for production per shift is much greater than with room-and-pillar mining since the coal haulage and mining are essentially both continuous operations.

Against these advantages of the longwall system are several disadvantages, some of which can render longwall unworkable. A soft roof or floor, or a roof too strong to cave, will make the system untenable. Discontinuities in the seam such as rolls, clay veins, displacement faults, or the presence of gas wells, will negate many of the advantages of the system. Because of the limited vertical range of the supports, too wide a variation in coal thickness cannot be tolerated. In addition to these physical problems, there is the economic disadvantage of moving the system from one panel to the next.

Despite these problem areas, the advantages tend to outweigh the disadvantages in most cases and today there is a noticeable trend in the increase in use of long wall mining. The longwall system consists of a combination of three basic components: the support system, the mining machine, and the haulage system (Figure 13). These components fit in a space 10-22 ft. from the face and are designed for proper maintenance and permit travel by the face crew along the longwall face.

SUPPORT SYSTEM

The support system consists of interconnected hydraulic jacks with roof and floor bars or canopies. They are self-advancing as well as capable of advancing the face conveyor. Each support has from 2 to 6 legs, with each leg's support capacity up to 150 tons or slightly more.

MINING MACHINES

Two types of mining machines are used in the United States, the Planer and the Shearer. The planer (or plow) rests on the floor of the seam and is pulled along the face in front of the armored conveyor with a chain. Non-rotating bits cut a thin layer of coal and deflect it onto the conveyor. While planers may be either partial or full seam height, most of those used in this country are high-speed, full-seam height units which travel at 75 ft./minute and cut 3-6 inches of coal from the face (Figure 14).

Shearers are narrow continuous miners which cut coal through the action of rotating drums. Each web, or cut, is 24-30 inches wide and the machine is designed to ride on the face conveyor. The shearer pulls itself along a stationary wire rope or chain, up and down the conveyor. Shearers may have single or double cutting drums, and these may be fixed or moveable. To avoid leaving uncut coal or cutting rock, the use of the single fixed drum is limited to seams with a uniform thickness and little or no undulations. The ranging single drum shearer permits mining in undulating areas, however, if the seam thickness varies, two passes are needed to mine the full seam height. A ranging double-drum shearer permits the full seam to be mined in one pass (Figure 15).

The drum diameter of the shearer is normally 2/3 of the seam height, cables and water hoses are handled automatically with a specially designed flexible chain linkage, which also serves to protect the hoses and cables.

HAULAGE SYSTEM

The armored face conveyor is the most essential part of the system. Its primary function is to haul coal, however, it is flexible enough to allow snaking of the conveyor and has sufficient strength to permit the shearer to slide on top of it. The conveyor is usually no longer than 600 ft. and operates at chain speeds in the range 150-250 ft./minute. Most conveyors are 30 inches wide and made up in 5 ft. long sections (Figure 16).

At the head-entry side of the face, the armored face conveyor discharges onto an intermediate haul unit (stage loader) that either piggybacks or side-dumps onto a panel belt (Figure 17). The use of a stage loader prevents frequent stoppage of the longwall face for the shortening of panel belts and also obviates the problem of extending a belt inby the caved roof line.

There are about 80 longwall systems currently in use in the United States that are averaging about 600 tons per shift, including move times. There is a general view in the industry that longwall systems have the potential for high productivity if they can be kept running, but until recently, their overall cost effectiveness has been marginal. One company has recently reported a longwall face producing 12,395 tons in a single day on a one-time basis, and over 1,000,000 tons mined from the same face, in a one year period.

There seems to be a parallel between longwall and continuous mining in the United States; both systems have very high potential capacity but their low utilization prevents them from achieving it. In general, the most critical areas that reduce the utilization of the longwall system are head and tail gate ground-control problems, move times, machine breakdowns, and in some cases, outby haulage inefficiencies.

There are varying views on the rate at which longwall mining will become accepted in the United States coal industry. The most optimistic prediction is that 50% of the U. S. underground coal production will be mined by longwall methods by 1985, whereas the most pessimistic view suggests that only 10% will be about all that longwalling will ever achieve. Estimates of the fraction of U. S. coal that is geologically suited to longwall mining indicate between 30-70%. This, of course, is not a static number, since it varies as the technology changes. The Europeans, precluded from the use of room-and-pillar mining by their mining depths, have used the longwall in virtually all of their conditions.

SHORTWALL MINING

The Shortwall Mining Method has achieved a limited application in this country. There are about five systems in operation in the Eastern United States. The shortwall system uses a continuous miner to cut a depth of 9 to 11 feet per pass, instead of using a shearer or plow. The continuous miner cuts in one direction only and backs up along the face between cuts. The face lengths worked to date have been of the order of 150 to 200 ft. The roof is supported along the face by large special longwall supports with canopies which are cantilevered out a sufficient distance to allow room for the continuous miner (Figure 18). The coal is generally transported away by shuttle cars, although a form of continuous conveyor system has been tried.

There are several motivating forces behind the shortwall trials in the United States. The primary one is to achieve improved productivity with a lower capital expenditure than would be required for a longwall installation. A second reason is the greater flexibility in mining around the large number of oil and gas wells which have penetrated many coal seams in the United States. A third factor is that roof and ground control problems are generally easier to manage with the more rapid rate of advance of the face that results from a shorter face length.

There are some additional advantages of the shortwall method of mining. Control of coal dust is generally good. The overall ventilation has the directness and simplicity of the longwall but it does not have a localized dust problem. The cross-sectional area along the face for air flow is large. The face crew can stay on the upstream clean air side of the continuous miner. Because of the shorter face and the more open area for movement, communication and coordination of the operation is simplified. Compared to room-and-pillar mining, it uses fewer supplies such as roof bolts, rock dust, etc. The shortwall system also has the advantage of using the continuous miner, thus taking advantage of operator and maintenance familiarity and skill that have been accumulated with it. This same comment applies to the shuttle cars when they are used to transport the coal away from the continuous miner. When the shortwall system is stopped for reasons not related to the continuous miner or when the shortwall equipment is being moved, coal can be mined at other working places so some continuity of production can be maintained.

There are two important disadvantages of the shortwall mining method. The first is that since a greater span of roof is exposed between the face and the supports than in longwall mining, and the elapsed time before it is supported is greater, there is a potential for localized roof difficulty ahead of the supports if poor roof conditions exist. Shortwall mining is most successful under a friable but firm roof. The second disadvantage is that the transportation of the coal is not effective. The use of shuttle cars severely limits the productivity because of the waiting times involved. Systems based on shuttle cars have only a limited productivity advantage over room-and-pillar mining from which to offset the additional capital investment in the supports and the loss of production during moves from one face to another. Shortwall mining requires an effective continuous transport system in order to realize its full potential. The continuous transport systems used to date have generally proved troublesome, and improvements are currently under design.

Other limitations inherent in shortwall mining are the need for supports which are larger, more costly, and less easily handled than longwall supports. The recovery ratio of shortwall systems is not as high as for longwall systems unless the entry pillars are mined. Shortwall mining requires a seam height of about five feet, so it cannot be used in thin seams where longwall mining is applied. It is possible that shortwall systems will not be able to control massive sandstone formations except on very short faces where the floor is firm.

The unique feature of the shortwall system is its ability to utilize exisiting underground machinery. Its greatest area of application is in modest size operations where the overall capital investment can be minimized by using existing continuous miners for the dual function of development and shortwall mining. It appears that many of the desirable characteristics of shortwall systems such as lower capital cost, shorter move times, and greater flexibility can be more effectively achieved by simply using a short version of a longwall system.

THE TRANSPORTATION OF COAL IN UNDERGROUND MINES

The transportation of coal from the loader, continuous miner or longwall face is usually considered in three segments, namely, face haulage, intermediate haulage and main haulage. In a few hill-side type underground mines (punch mines) face haulage units normally transport the coal directly to the outside of the mine. In most instances, the intermediate haulage method normally used to transfer the coal from the face haulage to the main mine haulage system is also used for the main haulage.

TRANSPORTATION OF COAL IN UNDERGROUND MINES

1. FACE HAULAGE METHODS

In the preceeding paragraphs, a brief reference has been made of the types of equipment used to transport the coal from the mining machine to the intermediate and/or main haulage system in use. Since other speakers will discuss the various underground transportation systems in more detail later in this workshop, the following comments refer to generalities pertaining to the equipment currently used for coal mine haulage.

INTERMITTENT FACE HAULAGE

(a) SHUTTLE CARS

The cable reel shuttle car, shown in Figure 11 represents the current standard of the industry for face haulage. The cars are simply underground trucks with a chain-conveyor bed to store and move the coal either onto or off the car. Power is supplied via a trailing cable which is wound in or out on a powered reel with a normal maximum storage of 500 ft. One manufacturer uses a torque converter and transmission to transmit power to the wheels, while most other manufacturers use electric traction motors to drive the wheels through mechanical gear drives. The latter type use direct current motors for traction almost exclusively.

Capacities vary with seam height. Although manufacturers generally market only a few basic models, these may then be ordered in a choice of several widths (standard, +12", +24", etc.), with several sideboard heights and even extended lengths. A rough guideline for "typical" shuttle car payloads follows:

Seam Height	Payload
. 36"	1 - 2 tons
. 36" - 55"	2 - 5 tons
. 55" - 100"	5 - 12 tons
. 100" - 180"	12 - 15 tons

Shuttle car speeds vary with floor conditions and clearances and speeds normally ranging from 300 to 375 feet per minute. Loads have little effect on speeds. Discharge times vary from 30-45 seconds when otherwise unrestricted and are independent of the load.

The disadvantages of shuttle cars include the following: The reach is limited by the cable length unless backspooling is practiced. Since each car must travel to and from the loader along the same path, two or three cars are the maximum which can be practically used. Cable problems are a constant source of downtime because the cables are subjected to constant pulling, bending, and abrasion. Haulage is, of course, intermittent with change-out delays built into the system. Longer waits are encountered as the distance from the discharge point to the face increases. The cable also represents a danger to personnel and is a potential fire source.

The advantages of the cable-reel car are often overlooked. The cars are flexible and adaptable. If one car is down, another can continue to haul at a rate of 60-75% of two-car capability. Since the power source is external to the cars they are relatively lightweight and compact (hence, maneuverable).

(b) ARTICULATED BATTERY POWERED HAULERS

A battery operated rubber-tired haulage unit with a ram-type discharge and articulated construction is shown in Figure 19. The car consists of a load carrying unit and an operator power source unit permanently connected by a flexible, articulated joint. Speeds are in the order of 350-400 feet per minute when empty and 250-300 feet per minute when loaded. Only one manufacturer is currently marketing this style car, and three models are available for various seam heights. Discharge times are 15-20 seconds regardless of load when discharging is unrestricted. Like the shuttle car, this car has a built-in delay while cars clear the change point. As the distance from the discharge point to the face increases, additional cars can be used since these cars travel a circular path with all loaded cars following one route and empties following a second route. Thus, any additional wait can be avoided by adding cars. While batteries give the cars flexibility, it is usually necessary to change batteries during the shift. A battery change may be made in 20 minutes or less in a well-designed facility. Because of the stringent regulations for battery charging stations, they are generally centrally located in the mine or on the surface with appropriate battery handling equipment available at each section changeout point.

Capital costs and maintenance costs are higher for the ram-dump cars than for shuttle cars.

(c) BATTERY TRACTOR-TRAILER UNITS

Battery tractor-trailer units have found wide acceptance in small, low-seam operations. The tractors are also useful for other duties such as hauling the man-trip between shifts. A tractor-trailer unit is shown in Figure 20. Several types of trailers, differentiated by discharge method, are marketed, including the chain-conveyor bed, ram-type, tilt bed, and drop bottom cars. The primary attraction of these units is low capital cost. Coal carrying trailers can be purchased for 10-20% of the cost of a shuttle car.

(d) FRONT-END LOADER OR SCOOP

The scoop or front-end loader was introduced into the mining cycle as a utility vehicle, primarily for cleaning entries and hauling supplies and parts. Several mines have begun using them as load-haul-dump (LHD) units, utilizing their self-loading capability. These trials have been sufficiently successful that second generation scoops with bucket capacities up to 200 cubic feet (approximately 5 tons) have appeared.

The scoop is basically a battery tractor unit with a hydraulically operated bucket attached to the front, as shown in Figure 21.

Dumping times are similar to those of the articulated-ram car at 15-20 seconds, and loading is accomplished by tramming the scoop into the coal pile. Load times in the order of 15-20 seconds are common for initial loads but increase as more maneuvering is required to fill the buckets. In general, scoop loading rates are comparable to those of a loading machine and speeds are comparable to other battery powered haulage units. The capacity of an LHD will be lower than a standard haulage unit in a given seam height.

Three advantages are readily apparent in using LHD vehicles. First, the need for a loading machine, a loading machine operator and possibly a helper is eliminated. Second, loading continues even if one unit is broken down. Third, while a loading machine is hampered by the long load times during clean up, the

other scoops(s) can begin loading from other faces while one of the units finishes cleaning up the prior cut. In fact, change out waits can be eliminated by working each scoop in a separate entry. (MESA has declared that only one place may be loaded on any given split of intake air). Other disadvantages are the superior cleanup ability of the scoop and the flexibility of the LHD unit to perform utility operations when necessary.

(e) DIESEL POWERED TRUCKS

Diesel powered haulage units currently used in coal mines are similar to the articulated battery haulage unit in operating principle. Speeds and discharge times are similar to those of battery powered equipment although backing speeds are generally lower due to poor operator visibility.

Diesel powered units are subject to special regulations to reduce potential health and safety dangers presented by the diesel exhaust fumes, fuel, and engine heat. In addition, special safety features are also incorporated by the manufacturers of the units. Primarily, government regulations call for large ventilation quantities and tight limits on the amount of CO and NO_2 emitted from the diesel exhaust. These limits are 50 PPM and 5 PPM respectively. Flame arresters (to prevent backfiring into atmosphere), exhaust scrubbers, compressed air starters, automatic shutdown for cooling jacket temperatures in excess of 212^o or low water level in the exhaust scrubber, are standard safety features of underground diesel engines. Diesel haulage units are currently available for use in seams as low as 42". Engine height is the limiting factor in producing lower units. The United Mine Workers of America have a long history of opposing the application of diesel equipment in union controlled mines. It is presumed that the rank and file are opposed because of health and safety considerations.

GENERAL DISCUSSION ON INTERMITTENT HAULAGE

Intermittent or modular haulage has been recognized as a bottleneck in materials handling in underground coal mining ever since the first shuttle cars were introduced. Conveyor schemes of many types have been introduced, lauded, and have faded away, while this seemingly inefficient method has remained. The reasons for this are primarily flexibility and reach. Flexibility is exhibited by the ability of the haulage unit to follow the miner or loader through any mining configuration and the ability to continue hauling even though one of the units is disabled. Reach is simply the ability to extend out from the discharge point as far as the mining machine must go. Continuous haulage schemes have always fallen short on one or both of these points.

Time studies and simulations of room-and-pillar mining systems indicate that change out time will represent from 15-20% of the available time for production. (This is defined as the shift time less travel, face preparation, scheduled meetings, breakdowns, lunch, servicing, etc.; this is the time in which the units and men otherwise are actually capable of coal production). In general, available time for production will range from 175-300 minutes per shift with an "average" value at 225 minutes. Thus, 30 to 60 minutes could be saved if suitable continuous haulage units were available. It must be recognized, however, that not all of this time will be additional loading time. In general, this time will be distributed proportionally among the remaining loading and hauling activities.

Additional time is lost in those working faces where the car cannot get back to the change point at or prior to the time it is cleared by the previous car. The maximum distance from the discharge point to the change point at which an additional wait will not be encountered can be calculated by balancing the load and change out times

with the haul and discharge times. Such calculations clearly show that one of the major advantages of cars without trailing cables is that by increasing the number of cars in use from two to three effectively doubles the maximum haul distance over which an additional "wait" is not encountered.

CONTINUOUS FACE HAULAGE

Attempts to establish continuous face haulage have been made since the introduction of the continuous miner. Prior to the past few years all these have involved either chain or belt conveyors of one type or another. Various continuous haulage schemes are discussed in the approximate chronological order in which they have been evaluated in underground coal mines.

(A) BRIDGE CONVEYORS

The earliest attempts at continuous transportation were long chain conveyors which were attached to the boom of a continuous miner and rode on the sides of a fixed chain conveyor. The latter conveyor extended back to the panel belt conveyor. The bridge was approximately 20-25 feet in length, allowing the mining machine to advance this distance before stopping to "pan-up" or add sections to the fixed chain conveyor. At this point, the chain and tail sections were disconnected, the tail section was extended, new sections of pan and chain were added, and the chain and tail section reconnected. Although this task seems arduous, it could normally be accomplished in 6-12 minutes.

This process is repeated until the full length of the room or entry is driven. Crosscuts are turned using the ability of the bridge to swivel about the connection point on the fixed conveyor. However, the maximum crosscut depth which can be driven from one entry is equal to the length of the bridge plus the length of the miner minus one-half of the entry width. For most systems this is 30 + 20 - 10 = 40 feet.

The bridge conveyor system restricts a unit to working one entry at a time since the fixed conveyor has to be dismantled to tram the continuous miner from the place. This restricts its use to mines where men can work under unsupported roof or where the roof is supported as the mining machine advances. In addition, the delay encountered every 20 feet is as much as a mobile continuous miner would often experience when place changing. For these reasons, the bridge conveyor concept is used only with the auger miner (Figure 5), which uses skid tramming and cannot place-change readily.

(B) EXTENSIBLE BELT

The extensible belt is similar to standard belt conveyors except that the headpiece consists of a number of moveable pulleys around which the belt is woven. As the tailpiece is extended the pulleys are drawn toward the middle of the headpiece, reducing the amount of stored belt. These units generally contain from 200 to 400 feet of stored belting allowing the tailpiece to be advanced from 50 to 200 feet without stopping to add belt.

The tailpiece of an extensible belt is moveable and acts as a feeder for the belt proper. As the belt is advanced, quick-coupling idler stands are added. The idler stands are established by connecting bars locked into the adjacent stand.

As with the bridge conveyor, the extensible belt can only be used where roof support is concurrent with the continuous miner or where work is permitted under unsupported roof. This limitation, along with the restricted crosscut lengths, have relegated the use of the extensible belt to room driving with narrow pillars and with

either continuous miner-mounted bolters or timbering with the aid of jacks located on the continuous miner. Ripper-type continuous miners are especially suitable to this system since the sumping and cutting actions are accomplished with the machine frame remaining stationary. Later types of continuous miners do not have this feature and the use of extensible belts has diminished.

Unlike the bridge conveyor which is used in seams as low as 28", extensible belts have not been designed for use in seams less than 4 1/2 feet in height.

(C) MODULAR EXTENSIBLE BELT

A variation of the extensible belt has recently been introduced using modular units in which conveyor belt is not added or taken off. When retracted the unit is 20 feet long and when extended, it is 150 feet long. The units are self tramming and are intended to be used in sets of two, three or more. In this way it is possible to turn crosscuts and to develop several entries. These units appear to have solved several of the shortcomings inherent in the single extensible belt system. However, information on the feasibility of place changing with these units has not been documented.

(D) BRIDGE CARRIER SYSTEMS

An extension to the bridge conveyor concept was developed in the late fifties and early sixties utilizing a mobile bridge carrier and two bridge conveyors as shown in Figure 22. The first conveyor bridges from the continuous miner boom to the inby end of the carrier and the second from the outby end of the carrier to the panel belt. Both the carrier and the panel belt are equipped with rails on which the bridges can slide. While the length of each unit can be varied, normally the bridges and the carrier are each 35-45 feet in length. Early units used chain conveyors to overcome height limitations with belt conveyors. However, units have recently been introduced using a conveyor belt that slides on stainless steel decking. Another innovation is the addition of a second bridge carrier and a third bridge to increase the reach of the system.

The bridge carriers are geared to the same tram speed as the continuous miner; thus, place changing is feasible with these units. Since the conveyor extends from the belt to the mining machine, mobility of the bolter is a problem unless two bolters are used.

Reach limitations and limited turning radii dictate that crosscuts must be turned on angles of 60° or less. Three entries are the maximum that can be driven with a three-unit (two bridge conveyors and a bridge carrier) system and five entries with a five unit system.

Mining accurately according to plan is critical with these systems since a crosscut driven more than a few feet off line may make it impossible to reach the outside entry, or if turned too soon, may cause the next belt advance to be tailor fit by cutting the belt into odd lengths.

(E) MODULAR BELTS (CASCADING CONVEYORS)

In the past 25 years several schemes have used a series of short, independent, but interconnected conveyor "cars" which could follow the continuous miner through the cuts by extending and retracting as shown in Figure 23. In the retract position, these conveyors are designed to slide partially on top of the other. As the units are extended they are designed to "track" the miner, and thus can maneuver through right angle crosscuts. Reach and seam height have been limiting factors in these designs. The conveyor

units could be compressed only so far and sufficient seam height was required to stack the conveyors. While many prototypes have been introduced and described in the literature, modular belts have never advanced beyond this stage.

(E) SERPENTINE BELTS

One of the newest approaches to continuous haulage is the serpentine belt system. This system consists of a pleated belt capable of turning corners and a wheeled, jointed conveyor structure. While the unit was exhibited several years ago it remains in the prototype stage, reportedly due to failure of the belt to remain on the idlers when turning corners in undulating floor conditions. The system is designed to be pulled by the continuous miner so that the function of the bridge carrier operator would be eliminated. The maximum belt length (and thus the reach) for this unit is unknown, but should be equal to the trailing cable -- an important advantage over other units.

One variation of this system is currently being tested in Illinois. Here the belt and structure are suspended on monorail beams supported by roofbolts. (Figure 24). Undulations are eliminated and the belt is reported to be operating successfully. Switches are used at junctions to guide the belt to the appropriate working face.

(G) ARMORED CONVEYORS

Armored conveyors are used exclusively on longwall faces and are an integral part of the mining system. While the primary function of the armored conveyor is to haul coal from the longwall face, in its present form it has other important functions, namely:

1. It must have sufficient structural strength to withstand the coal shearer riding on top of it, or in the case of a plow face, provide guidance for the plow and resist the heavy side pressures exerted upon it.

2. The joints must provide flexibility during the snaking of the conveyor up against the face after the shearer or plow has cut the face.

3. The conveyor must have a high capacity.

4. The conveyor must provide trouble-free operation over a long life span.

The armored conveyor can be driven by one, two, three or four driving units on either or both sides as shown in Figure 16. These drive units consist of an electric motor, fluid coupling and reduction gearing. The operating speeds of most chain conveyors are between 150-250 ft./minute, the upper limit trending towards matching the increased capacity of modern coal shearing machines. The armored conveyors in use are usually 30" in width and constructed of triangled steel plate sections each 5 ft. in length and fabricated in one piece with 5^{o} flexibility at each end. Double inbord chains have been used extensively in the past, however, the current trend is to a single large chain center-strand or two smaller size center-strand chains. In order to cater for tension in the chain, excessive wear associated with re-circulation of fine coal and effects of snaking of the conveyor, chains and flights are of a robust design and special guides are provided on the conveyor to ensure the chain is fed into the race properly. In most instances, the conveyor is driven from both ends of the face, however, because of the space needed in the tail entry for the tailgate drive, problems can occur if poor mining conditions occur.

In general, the armored conveyor is the most essential part of the longwall system and probably the weakest link. Although longwall faces have been worked up to 900 ft. in length, experience has shown that 600 ft. is more reliable -- primarily due to the limitations of chain pull and drive arrangements on current armored conveyors.

(H) HYDRAULIC TRANSPORTATION

The pumping of coal slurries has been successfully demonstrated on the surface with the Cadiz to Cleveland pipeline in Ohio and the Black Mesa pipeline in Arizona. Recently, an underground coarse coal pipeline was installed at a Northern West Virginia mine and it is reported in the literature that the installation has proved successful and is economically competitive with mainline track and belt installations.

This project has been followed by the installation of a 10" diameter flexible hose that pumped directly from the continuous miner to the pipeline. The hose was fed from a portable crusher-hopper-pump unit designed to tram with the continuous miner. The hoses, one for coal slurry and one for fresh water, were mounted on wheeled dollies. Slack was taken up by forming a "U" in an adjacent entry or crosscut. Figure 25 illustrates the concept used.

Hydraulic face transportation should provide a solution to several problems common to conveyor systems. First, because the hose is flexible it can follow the continuous miner through tight clearances. Second, the reach of the hose should be equal to (or longer than) the trailing cable length on the continuous miner, thus allowing rooms to be driven with this system. While place-changing can be accomplished with the hose it does introduce a delay into an otherwise continuous system.

Hydraulic transportation will also solve the problems of dust and spillage which accompany face conveyor systems. What new problems will be created remain to be seen, although at present none are foreseen.

(J) PNEUMATIC TRANSPORTATION

Research has been conducted, principally in England, by the National Coal Board, and in the United States, by the Bureau of Mines, on pneumatic transportation of coal. While some success has been demonstrated by laboratory experimentation on the surface, and vertical pumping in a shaft, little hope is seen in actual underground mine usage. Coal today is sprayed with water to allay dust as it is being mined and this will normally make it unsuitable for pneumatic transport. In addition, there is the attendant static charge and spark explosion potential that may make this method untenable in other than shaft applications.

2. INTERMEDIATE TRANSPORTATION

Intermediate transportation systems are designed to transport the coal from the face haulage discharge point to the mainline system. There are only a few types of intermediate systems in use today. These are the panel belt systems either discharging into the main belt or into mine cars, and the gathering locomotive method, dropping off empty mine cars at the mining sections and hauling loads to gathering rail sidings that are picked up by the main line locomotives.

Except for the use of hydraulic mainline transportation and small mines hauling from the coal face to the surface with battery powered equipment, mainline transportation differs from intermediate transportation only in size, scope and permanence of installation.

The fundamental difference between face transportation and other transportation should be appreciated. Face transportation is normally the controlling factor in production; that is, the object in selection or design is simply to build as much capacity as possible into this system. Intermediate and main haulage are problems in providing adequate capacity in the most economic manner.

BELT TRANSPORTATION SYSTEMS

As mentioned earlier, belts are normally used as the intermediate transportation unit. They generally receive coal from a ratio feeder and discharge the coal onto the main transportation system, which is usually either another belt or a track haulage system (Figure 26).

In general, belts may be characterized as high capacity, reliable coal haulers with high capital, and low operating costs. Intermediate belts servicing one section are generally 36" wide and belts hauling coal from multiple sections are 42 or 48". Federal law requires that all belts must be isolated and that air used to ventilate the belt must be discharged directly into the return entries. In addition, water lines must be installed parallel to the entire conveyor length with outlets every 300 feet. Water or foam fire control systems must be maintained along the length of the belt. An alarm system capable of stopping the belt drive must be part of the belt fire control equipment and the fire sensor must also detect the location of a belt fire.

The belt conveyor system is composed of the belting, the structure, the drive and take-up mechanism, the loading and transfer points and the safety devices discussed earlier. Today, conveyor belts used in coal mines are made from polyester, nylon, and other synthetic materials. These materials provide strong flexible belts which are characterized by low stretch (less than 1 1/2% of the length). Steel wires are also used in belts where high tension applications, such as slope belts, are used to convey coal out of a mine.

Belt coverings are usually made from fire resistant materials, such as neoprene, in multi-ply belts. Cover thicknesses vary, but for coal mine applications top thicknesses of 1/8 inch and a bottom cover of 1/16 inch are common. Woven carcass belts of 5/16 inch total thickness are also used.

The strength of belts used today has been increased considerably and often 2 ply (or woven carcass PVC) belt 36" wide are used to drive panels 3,000 feet long, while 3 ply 42" belts will extend 4000-5000 feet. Most coal mines tend to standardize on motor drives where 75 or 100 horsepower motors are used for panel applications, and 150 or 200 horsepower motors are used for mainline belts. Single drives are common in the former and tandem drives in the latter. Where high production longwall faces are in operation these sizes are increased significantly and this will be discussed later.

Belt structure used today is generally of the floor mounted wire rope frame type, which facilitates easier extension of the belt and easier belt alignment. The latest step has been to suspend the wire rope from the roof, thus permitting easier cleaning. (Figure 27).

In recent years, belt capacities have been increased with the introduction of 35° and, in some cases, 45° idlers, together with the introduction of thinner, more flexible belts. Previously, when belts were less flexible 20° idlers were required. A capacity increase of slightly more than 25% can be realized with a change from 20° to 35° idlers.

Belt capacities are readily calculated from standard tables; however, for main belts serving multiple sections, the selection procedure is more complex. Belt speeds, method and rate of loading, willingness to delay feeder belts, and placement of surge bunkers, all effect the minimum belt size required. Simulation programs have been developed to aid in the selection of belt sizes.

Although it is difficult to generalize on the coal industry's practices, it appears that belts of 36" width predominate for single section service except for low capacity auger-type miners which normally use a 30" width, and some high producing longwalls that use 42" width. Belts serving two to six sections are generally 42" wide and for greater than six sections, a 48" belt will be used.

While it seems logical that belts serving multiple sections should be sized according to the total production from these sections, this is not entirely adequate. Sizing is also dependent on the maximum instantaneous load which can be expected. While this load can be adjusted in low production sections by cutting back on feeder rates and stopping feeder belts, the instantaneous load is primarily a function of the number of production units (adjusted for shuttle car payload) only. Thus, the belt sizes tend to be uniform when serving a given number of sections.

RAIL HAULAGE

Underground rail haulage is similar to that on the surface except for the reduction in scale. At present, all locomotives are electric with either trolley or battery supplied power.

The mines which utilize all-rail haulage from the shuttle car discharge point to the surface or shaft bottom usually either load into mine cars using a push-pull system as shown in Figure 28, or, where sufficient entries are driven, use a loop system as illustrated in Figure 29. In the former, five or six cars are pushed onto the dead end track. After these are filled, a locomotive must remove them and switch in a new string of empty cars. This switching usually requires ten minutes or more to complete. In addition, shuttle cars encounter long discharge times when the load must be split among two mine cars. These times will range from 1 to 1 1/2 minutes in comparison to a non-delayed time of 30 to 45 seconds.

With loop loading the switching delay is eliminated. Empties are simply added to one end of the loop and loads are removed from the other end. The lengthy shuttle car discharge times that result when dumping into two mine cars is still retained unless a portable feeder-car spotter is used. Ideally, mine cars should be sized to take whole shuttle car multiples so that a single shuttle car does not have to distribute its load into two or more mine cars. The normal procedure is to use smaller locomotives (20 tons or less) to service the sections and deliver loads to, and pick up empties at, the marshalling points. By doing this 60 pound track can be laid on steel ties in the panels and only a minimal amount of grading and ballasting is required.

BELT-RAIL HAULAGE

Where belts are used for intermediate haulage, several belts may discharge onto another belt which then discharges at a rail loading station. Since these stations will be in service for a year or more, they are generally automated and can be left unattended. A loop-type loading track is always used.

As the belt carries the coal to the mainline track, larger capacity cars are generally used in comparison to operations with rail haulage from the face. Where haulage distances are very long, (for example, 5 or more miles one-way) or where sections are widely scattered, two-level rail haulage with marshalling areas may still be used in addition to the belt. Nevertheless, it is probably more common for the loads to be hauled direct to

to the main mine discharge rotary dump.

3. MAIN LINE HAULAGE

Main-line haulage systems are permanent installations designed to allow the locomotives to travel at high speeds. In large mines two way track haulage is used, with one track for inbound traffic only (empties) and the other for outbound traffic (full cars). Main-line rail will weigh 85 lbs./yd, or heavier and locomotives will generally range up to 50 tons per unit (Figure 30). Rail ties are treated wood, switches are automatic, and curves are placed on radii of 300-500 feet or more, allowing rapid travel. Block signals are used to keep traffic well spaced. Speeds on mainline track reach 12-15 MPH on well maintained systems. The underground track haulage system consists of the track, trolley and feeder line, locomotives, cars and various controls such as switches and block signals. These components of the system are discussed briefly below.

As mentioned earlier, track sizes usually range from 60 to 90 lbs./yd. for coal haulage applications. The lighter sizes will be laid with steel or armor-clad ties allowing quick advance or retreat in face areas. Minimal grading and ballast are used in these applications. The heavier rail is used for main line haulage. Here the track is spiked onto treated wooden ties and the roadway is well graded and ballasted with crushed slag or limestone. The lighter track described above can be advanced more than twice as quickly as the main line track.

Power is supplied through a trolley line carrying direct current at usually 250 volts, and rectifiers are required at frequent intervals to maintain proper voltage.

Coal haulage locomotives may range from units weighing less than 10 tons each and used to provide a gathering service, to 50 to 60 ton units for use on the main line haulage. All are powered by direct current motors to obtain proper speed control. Diesel locomotives are used in metal and other types of mining but none have yet been applied in coal mines. Battery locomotives are sometimes used for man and supply haulage but are rarely employed for coal haulage.

Mine cars range from 5-10 ton capacity (in older or small mines they may be as small as 1 ton) when loaded by shuttle cars, to 20-25 ton units where used for mainline service only. The cars are either solid bodied (with swivel couplers) and can be turned in a rotary dump, or are drop bottom type. The solid body cars are by far the most common.

Controls include automatic or manual switches, runaway switches, block signals, and central dispatching.

HYDRAULIC PUMPING OF COAL

Once proven feasible, secondary and main line pumping of coal appears to offer many economic benefits when compared to rail and belt systems. Since it will eliminate the dust and fire problems of belts there will be no need for fire sensing and a deluge system. Moreover, the necessity to isolate the haulage entries (either to control the air velocity to no more than 250 feet per minute with a trolley or to divert the air into the returns with belt) will fall away. The fire and shock hazards of trolley wires are also eliminated, as are spillage and the costly controls required for belt or rail systems.

While there are undoubtedly many benefits there is also much work to be done. Pumping coal from a single section American mine has been accomplished, although the ability to pump from several sections has yet to be demonstrated.

In summary, pumping appears to be environmentally and operationally advantageous. Whether it will prove to be technically and economically sound is yet to be determined although the answer appears to be positive for simple (one source) networks.

COAL INDUSTRY PRACTICE

There is no clear trend or pattern of usage for rail and belt haulage in the industry. Many small mines use track haulage and many large mines use an all-belt system. Low seam heights appear to favor all-belt haulage. Much of the application seems to be based on custom within a mining district. The sole trend apparent in the industry is toward using belt for intermediate haulage. The greatest potential for the future lies with hydraulic transportation but considerable research and development is needed before it becomes commercial.

Table I has been compiled to illustrate the amount of equipment used for transportation in underground coal mines. This data was derived from the 1975 edition of Bituminous Coal Facts, published by the U. S. Bureau of Mines.

TABLE I

1975 UNDERGROUND COAL MINE HAULAGE DATA

Total U. S. Bituminous Coal Production (tons)	607,774,000
Underground Mining (tons)	292,827,000
Number of Underground Coal Mines	2,292
Estimate of miles of Underground Track	2,600
Number of Mine Locomotives	3,427
Tractors - Rubber-tired	2,388
Trailers - Rubber-tired	1,708
Mine Cars	43,921
Shuttle Cars	7,070
Gathering and Haulage Conveyors	5,187
Miles of Belt Conveyors	1,727

THE TRANSPORTATION OF MEN AND SUPPLIES IN COAL MINES

An important phase of underground haulage is the safe and efficient deployment of mine workers to their working places. With the continual increase in cost of generally more productive equipment and the increasing cost of labor, it is important to minimize unprofitable and fatiguing travel time. The total travel time in many operating underground coal mines today exceeds one hour or about 12% of the working shift.

The transportation of men in a rail haulage mine is normally by specially constructed vehicles that carry say 30 men, and run on the main line rail haulage system. Frequently, use is made of specially designed man trip cars (Figure 31) or "jeeps". These latter vehicles are generally self-propelled and convenient for use by mine supervisors, and because of their versatility, used for on-shift delivery of spares or general supplies necessary in the mining areas.

Mines that employ conveyor belts for either main or intermediate haulage sometimes transport men and supplies on the conveyor belts by designing the belt system to be reversible. In such cases, the belt speeds are reduced for safe man riding and strict regulations are in force in regard to clearances between the belt, roof and sides; required illumination, design of loading and unloading stations, etc. Moreover, provision must be made for the removal of all things being transported at each transfer point of a conveyor, and then reloaded onto the next conveyor.

In most cases where conveyor belts are used as the main haulage system, track is laid in an entry parallel to the conveyor system and men and supplies are transported by means of special track vehicles to and from the face areas (Figure 32).

This rail haulage is normally much lighter in construction than main line haulage (40-60 lbs./yd. rail as compared with 80-120 lbs./yd. rail) and is consequently less expensive to build and cheaper to maintain.

Where producing sections are serviced by intermediate or secondary belt haulage and main line systems, battery powered trucks are becoming more popular for the transportation of men and materials. Being rubber-tired, these vehicles are extremely versatile due to their freedom of movement, and are able to be used for a wide variety of jobs in a mine.

Supply cars pulled by tractors are particularly versatile since trailers used for different purposes can all be hauled by a single tractor. All rubber-tired systems of haulage require a stable smooth roadbed to attain reasonable haulage speeds. In recent years, several methods have been devised for transporting supplies trailers on the main track haulage system. These methods include either dual sets of wheels for rail and roadway use, or track dollies to carry supply trailers from the mine portal to the inby end of the track haulage system.

In any haulage system that is used for men and supplies, it is essential to have the least number of transfer points to ensure an efficient system. The transfer of materials requires manpower and the transfer of men uses time which otherwise could be used for coal production.

In the case of mines using an all track haulage system, the scheduling of the transportation of men and supplies is extremely important. Where possible, this facet of the mining operations should not interfere with the hauling of empty and full cars to and from the producing coal mining areas.

SOME LIMITATIONS OF CURRENT TRANSPORTATION SYSTEMS AND ACTIVE RESEARCH IN PROGRESS

The transportation of coal is one of the major restrictions to higher production and productivity in underground coal mines. The production capabilities of presently available coal extraction machinery far exceeds the capacity of most existing haulage systems for moving the coal or waste rock from the face to the surface. All elements of the transportation problem in a coal mine, including the transportation of men and supplies, are currently being investigated by mining companies independently, and on a national basis by the United States Bureau of Mines, through their Research and Development Program.

The major thrust of this development work has been toward alleviating the intermittant face haulage problem, and ensuring that changes in one part of a haulage system do not lead to bottlenecks in another part of the haulage or mining system.

The following paragraphs review the major limitations of the existing transportation systems used in coal mines and highlights the research activities in progress.

SHUTTLE CARS

The evolution of face haulage has gone from cyclic (animal-drawn tubs or cars) to continuous (shaking conveyors) back to cyclic (shuttle cars) and is currently edging into continuous systems again. The ever-present need is to be able to remove the total production of the face machinery without reducing face flexibility. The tremendous advantage of shuttle cars is that they can service any working face in their range with a minimum of face-to-face transfer time. Also, a breakdown of a car in a multi-car system does not necessarily mean the loss of all production, and, in a balanced system, they are reasonably productive. Nevertheless, there are incentives to remove change-out time from the list of production delays. Investigations are currently in progress to develop a shuttle car that will transport more coal per working cycle without compromising on vehicular performance, overall size, or personnel safety standards. Also, evaluations are currently being made on the practical application of automated cableless haulage systems and its effect on safety and efficiency in underground coal mining.

Developments by industry include attempts to free the shuttle car from its dependence of the electric trailing cable. One large coal company has worked with a system employing gas and oil accumulators and a hydraulic drive system. They have also studied the use of the electrical conversion of kinetic energy for the drive system. Both these developments attempt to take advantage of the short duty cycle of the shuttle car between visits to a fixed energy input point. Batteries are unable to be used this way because of their low energy input rates and limited life under deep discharge cycling.

It should be noted that continuous haulage, although desirable, will not alleviate the delays necessary for checking for methane, roof bolting or tramming equipment between faces.

BELT CONVEYORS

Two major inadequacies are currently being investigated and should lead to improvements in the near future. The first is that conveyor belts do not go around corners easily. The corrugated or serpentine belt may be the answer for cornering, but its high cost and difficulty in splicing casts doubt on its ready acceptability. Short of complicated cornering devices for flat conveyor belts which turn the belt on its side, the serpentine belt is the only item on the horizon for continuous face belts. Thus, the serpentine belt and some versions of the cascading mobile conveyors will continue to be

tested extensively in the next few years. High cost and the total loss of production during breakdown, are serious deterrents to these systems. The second problem is in the speed of erection of conveyor systems. Generally, they are slow to install because each roller frame is placed by hand. Improvements have been made with slotted-bar side frames, rope frames, and semi-mobile drive units. Extensible belt drives were an attempt to solve this problem of slow installation. The United States Bureau of Mines is currently funding additional research to reduce belt change times, belt-drive moveup times, improved belt transfer point designs, belt cleaning arrangements, belt training and other related projects.

Other major projects under investigation that relate to conveying are multi-unit cascading continuous haulage, auto-track bridge conveyor train, the serpentine conveyor face haulage and a conveyor belt extender.

ARMORED FACE CONVEYORS

Since the production benefits of a longwall installation comes from the face itself and not the drivage of the gate entries, incentives exist to use broader or wider faces. However, the practical limit to face width is largely governed by the strength of the chains forming the armored face conveyor. When the start-up stress created by a fully loaded chain conveyor exceeds the strength of the chain, the chain breaks or is stalled, and excessive downtime frequently occurs. The practical limit of longwall face length has generally been accepted to be about 600 ft. Thus, there appears to be a need to develop either longer face conveyors that are reliable, or cascading systems or back-to-back conveyors. With the high degree of success currently being experienced in some recent longwall installations, it has been said that the armored face conveyor is a limit to the production potential from the system. Current developments by the United States Bureau of Mines and manufacturers to design and build high capacity conveyors to handle in excess of 1000 tons per hour with surges of 20 tons per minute, will serve to increase face productivity as well as overall coal extraction rate.

In the shortwall mining system, it has been shown that over 50% of the available mining time is lost when shuttle cars are used to haul coal from the continuous miner. As a result of this, a research program has been initiated to develop a continuous haulage system using an articulated chain conveyor on the face and a mobile conveyor in the head gate.

HYDRAULIC TRANSPORTATION OF COAL

The hydraulic face pipeline described earlier has proved to be both successful and economic. Further trials with coarse coal pumping are currently in progress by the United States Bureau of Mines and one large coal mining company. It has been announced that a commercial scale hydraulic system is to be installed at a large underground coal mine where the coal slurry will be pumped directly from the mining faces to the surface. With the aid of specially designed pumps, the coarse coal will travel from the working faces for 1.5 miles to an underground sump. From there, the coal will be pumped vertically 850 ft. to the surface and then over-land for 2.5 miles to a coal washing plant. In addition to providing the possibility of true continuous mining, the hydraulic transport system has the potential for: (1) a highly automated operation, resulting in low manpower requirements; (2) less handling of coal, that results in the elimination of spillage cleanup; (3) no dust generation, resulting in a reduction of rock dusting and explosion potential; (4) elimination of separate entry requirements for belt conveyors and (5) reduces the physical space requirements in an entry, or conversely, provides higher capacity in existing entries.

AUTOMATIC RAIL HAULAGE

It is conceivable that major underground coal mines with mainline rail haulage will use driverless centrally-controlled trains in the future. However, a need remains to provide safety for normal mine personnel who will be on or near to the tracks, also, there is a need to make the automatic system compatible with manned trips such as supply cars, jeeps and portal buses.

To investigate the subject of automated rail haulage, the United States Bureau of Mines is financing studies to demonstrate the practicality, safety impact and cost-effectiveness of such a system. Indications are that an improvement in productivity can be achieved by increased production of coal with corresponding reduction in manpower. Moreover, reductions in the projected haulage injury and fatality rates is expected to drop by a factor of two.

Studies indicate that automated rail haulage systems can be cost-effective in coal mines producing over half a million tons per year.

DIESEL-POWERED EQUIPMENT

Despite serious resistance to the use of diesel power in underground coal mines, it is conceivable that they will be used in the future for intake air, main-line haulage, - especially in drift mines where refueling can be done outside of the mine. Diesel locomotion is an excellent way to reduce trolley wire hazards.

Many people contend that a significant gain in productivity would result if diesel engine vehicles were used in place of electric cable shuttle cars in a section. However, it is said that high maintenance costs and difficulty in retaining skilled diesel maintenance personnel have offset the productivity gain and been prime deterents to the use of diesel power in underground coal mines. On balance, it seems that due to the absence of a clear advantage to diesel power over electric cable power in a section, and considering the long lead times and inertia that impede the eventual large scale use of any new system, it is unlikely that major developments will take place with diesel power face haulage.

Current research in diesel power is essentially intended to develop technical support for the use of diesel-powered vehicles underground. Reduction of pollutants, instrumentation for detection and warning, and improved ventilation are main areas of research.

BATTERY HAULAGE

Battery powered vehicles have been used in coal mines since 1910. With the increase in power demands that brought higher productivity in underground coal mines, the limitations of battery energy density, in terms of both weight and volume, led to a switch to trailing-cable-powered shuttle cars. The main advantage of battery power for vehicles is that it provides a self-contained energy source which eliminates the need for a trailing cable. However, the main disadvantages of battery power are the relatively limited amount of energy that can be stored compared with the energy requirements of many mining jobs and the need for frequent recharge. This disadvantage is compounded by the relatively low energy density of batteries which results in battery volume and weight taking up a significant percentage of the vehicle payload.

LIMITATIONS AND ACTIVE RESEARCH

In order to make battery-powered vehicles more competitive with electric-trailing-cable or trolley wire vehicles, it will be necessary to develop a cheap and durable battery with a duty cycle of 8 hours or longer and to have the capacity for quick recharge.

A battery that can be recharged as quickly as a fuel tank is filled will open up the market for battery-powered equipment. At the present, ventilation restrictions on track and belt entries are promoting the use of battery equipment.

MEN AND SUPPLIES TRANSPORTATION

The time required to transport men to and from their working places in the mine is a loss in potential production time. Although an increase in travel speed may minimize this time loss, the prime concern in men transport has been toward safety, that is, in conflict to an increase in speed. With the requirements of additional ventilation shafts by the 1969 Health and Safety Act, the industry seems to have judged the placement of additional combination shafts for air and portalling as the most cost-effective approach to reducing "man-trip" time. Research in the area of men and supplies transportation is almost completely supported by the United States Bureau of Mines. Two projects currently in progress are a feasibility study of a system to eliminate manual handling of supplies underground and a program to evolve new concepts for safer personnel cars.

GENERAL DISCUSSION

No large degree of innovative substitution is expected in the near to midterm. There are several reasons for this statement, and, for the most part, these reasons are contingent on a continued rate of growth in underground mining. One very strong reason against wholesale substitution is the tendency for mining operators to retain their machines in place as long as possible. Evidence of this is found in the unwillingness of some operators even to replace their non-permissible machines. New machines are a substantial financial burden, and have high set-up costs. Since mining systems are often tailored to the capabilities of the hardware, a change in hardware type frequently means a redesign of the mine system. The continued use of loading machines behind continuous miners and the use of all-track haulage systems are examples of operations which maintain serviceable, yet conceptually obsolete equipment.

The principal reason for slow substitution is the conservative approach of operators to innovation. On examination, these fears are understandable. Because of the inherently high capital risks in coal mining, operators require proof of performance before introducing new machines. Since there is no competitive edge which results from being first, this "wait-and-see" attitude, of necessity, results in long lead times.

CONCLUDING REMARKS

No reference has been made to the handling of coal, men and supplies in vertical shafts at coal mines in the U. S. A. This omission has been intentional, since, by and large, shaft hoisting of coal accounts for a small percentage of the overall coal production from underground mines in the industry. Where vertical shafts are used, they are generally less than 1000 ft. in depth and the hoisting facilities tend to be elementary forms of hard rock mine installations.

Many of the older shafts in use for the transportation of men and supplies are rectangular in shape and are equipped with automatic elevators. In the more modern circular, concrete lined shafts required to hoist coal at rates in excess of, say, 500 tons per hour, skip conveyances are usually used that have a capacity of up to 20 tons. Such production shafts are often equipped with electrically driven drum type hoists whose characteristics are designed on shaft depth, hoisting rates required and pay load capacities.

CONCLUDING REMARKS

Men and supplies are normally conveyed in an independent and separate shaft which leaves the production shaft free to hoist coal with the minimum amount of interruption.

This paper represents a general overview of coal transportation and materials handling in underground coal mines in the United States. The intermittent nature of face haulage in the traditional room-and-pillar mining sections continues to impede the production potential, however, in general, the intermediate and mainline haulage systems are adequate for this method of mining.

In recent years there has been a trend to increase the use of longwall mining at mines where suitable conditions exist. In those instances where the longwall equipment has been successful, the inherently continuous nature of the system and high instantaneous cutting rates, have proved to be troublesome to handle by mainline track haulage systems. Hydraulic transportation systems, underground storage bunkers, or improved mine car loading and tipping facilities will be needed to ensure that high face production is not retarded.

It has been stated that the transportation segment of the overall cost of mining is a substantial amount. Belton has indicated that 30% of the total mine cost can be attributed to underground mine haulage, and of this amount, about a third is related to labor costs. On this basis, the potential savings per year or during the life of a property; it is worth the time and effort to design and install the most efficient haulage system that is appropriate for each underground coal mine. A study carried out by a consulting company has shown that for a 1.0 million tons per year operating coal mine, there is a potential savings of over $0.5 million per year if a 10% improvement can be made in the overall mine underground haulage system.

To achieve improved transportation methods for use in underground coal mines, it will be necessary to innovate within the legal constraints that are currently affecting the industry and this will call for better mine planning and selection of equipment. Since change takes place slowly in the traditionally conservative coal mining industry, research and development activities can never be premature.

The views expressed in this paper are those of the author and not necessarily those of Consolidation Coal Company.

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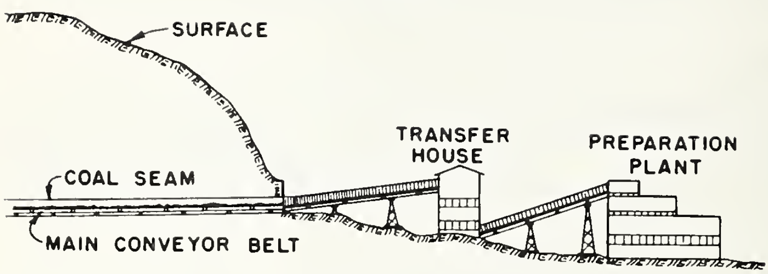
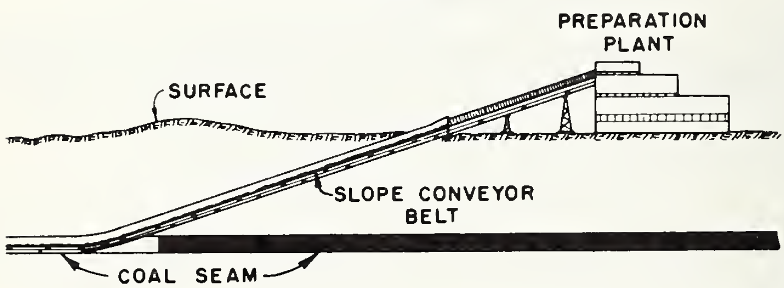
(a) Drift mine.



(b) Slope mine.



(c) Shaft mine.

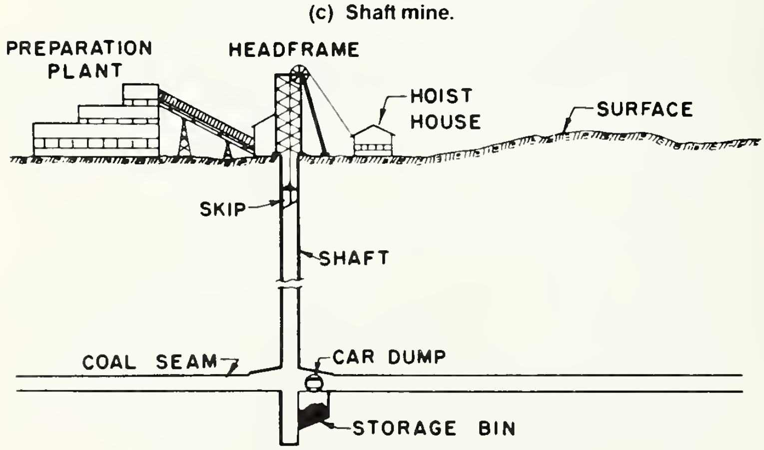
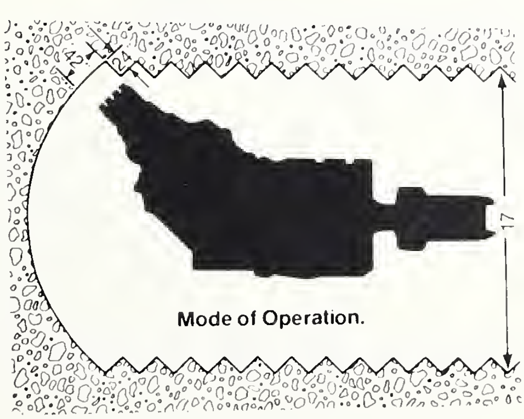


Fig. 1 - Methods of access in underground mines.

Fig. 2 - Oscillating milling or drum head miner.

Fig. 3 - Ripper miner.



Mode of Operation.

Fig. 4 - Borer-type miner.

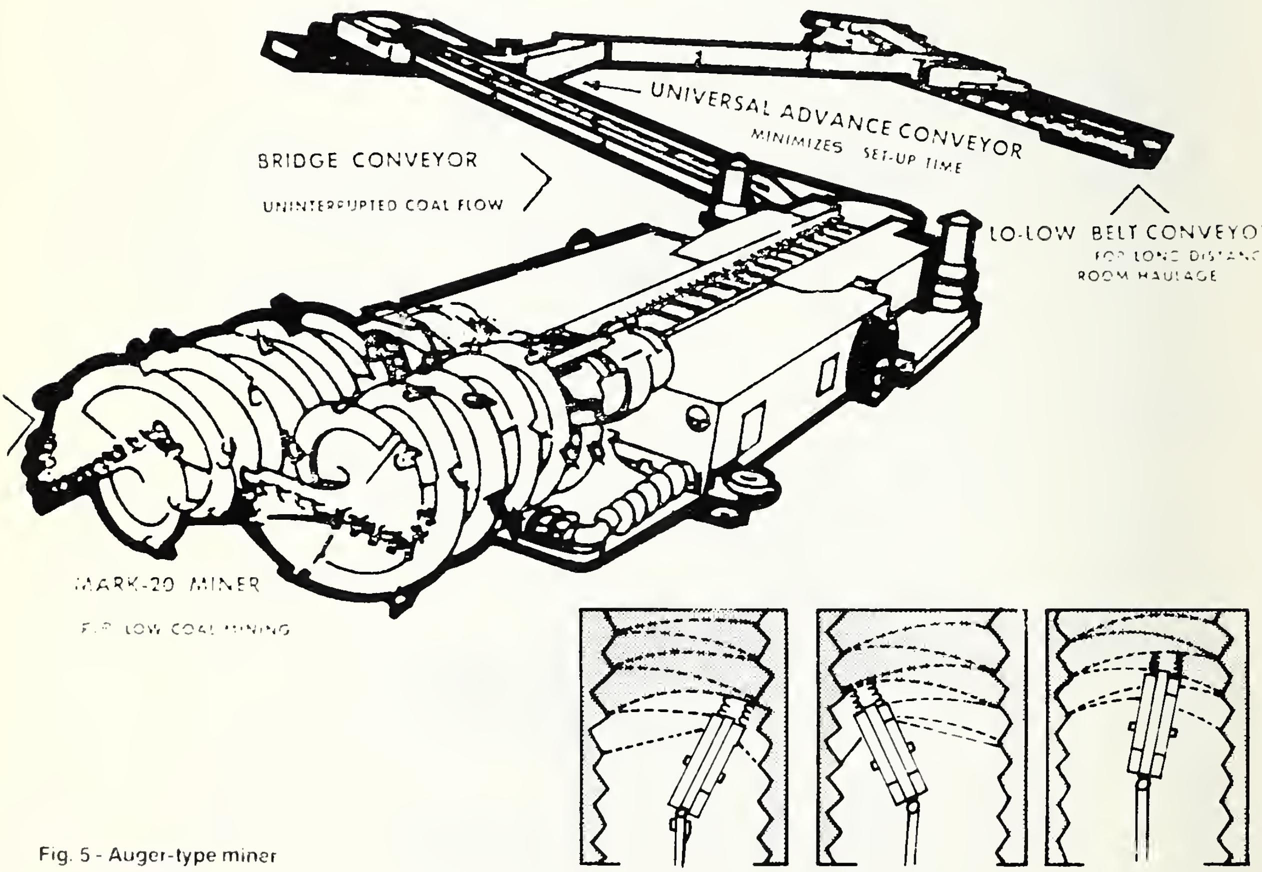


Fig. 5 - Auger-type miner

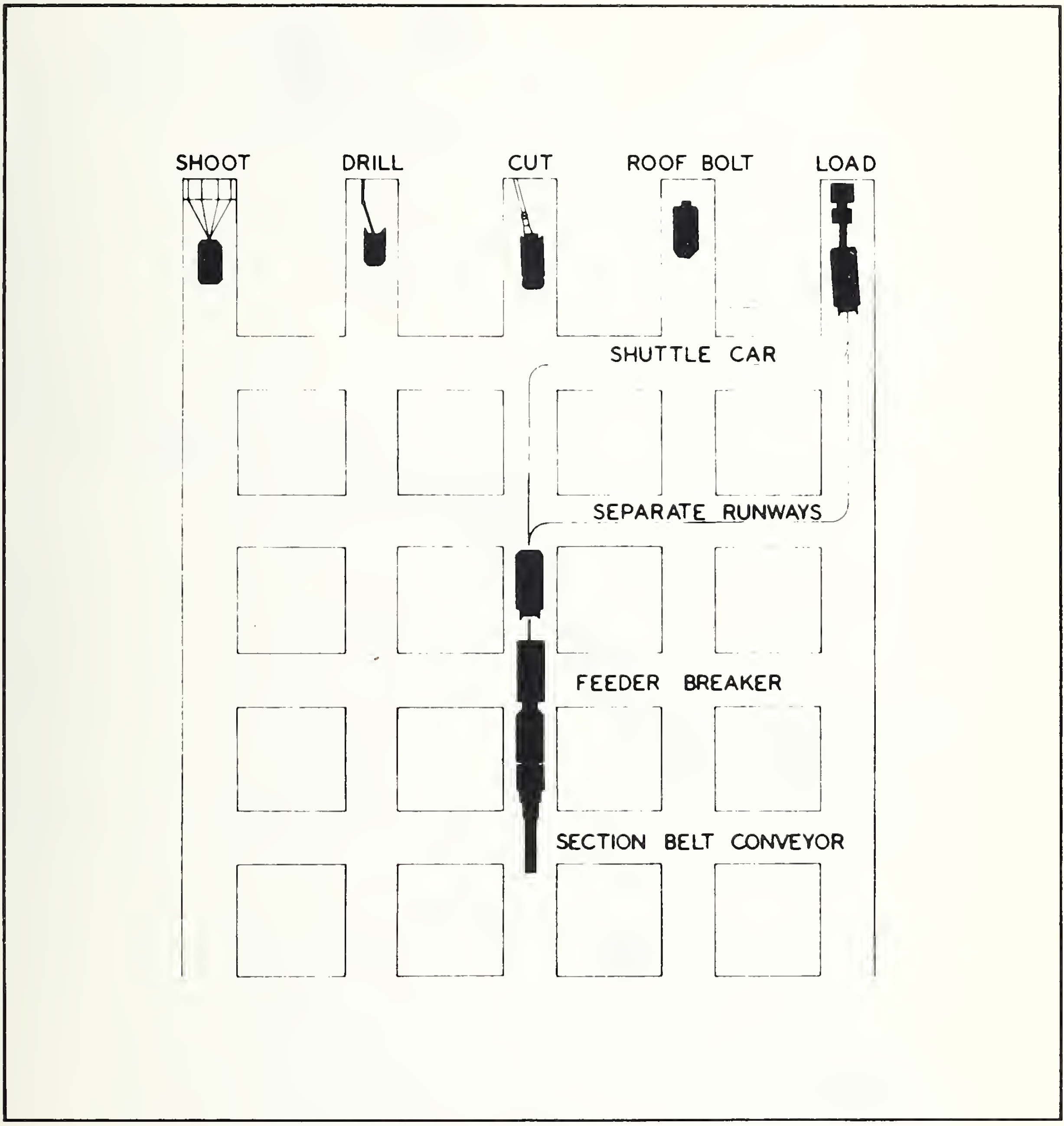


Fig. 6 - Conventional production-unit section haulage, shuttle cars to feeder breaker to section belt conveyor. With openings on 60-ft. centers, 20 breakthroughs are required for 2,300 ft. of entry and breakthrough drivage.

Fig. 7 - Coal cutting machine.

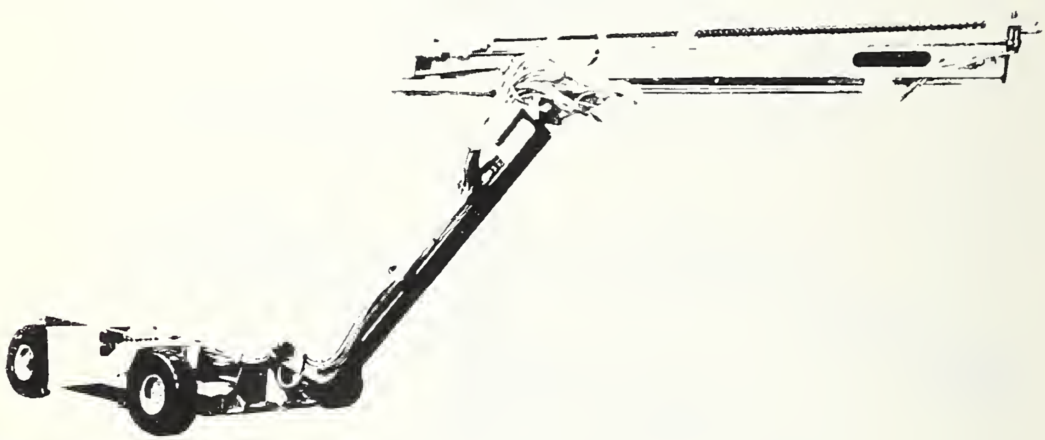


Fig. 8 - Drilling machine.

Fig. 9 - Gathering arm loading machine.

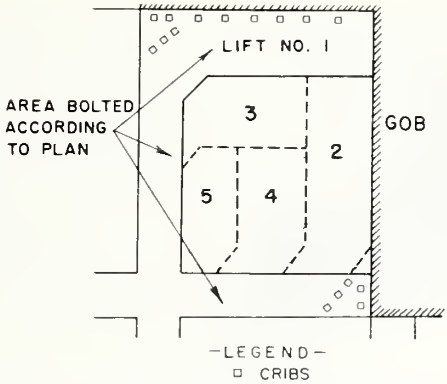


Fig. 10A - Detail sequence of mining a pillar by the open-end system. Many mines employ clusters of posts or multiple rows of posts instead of cribs.

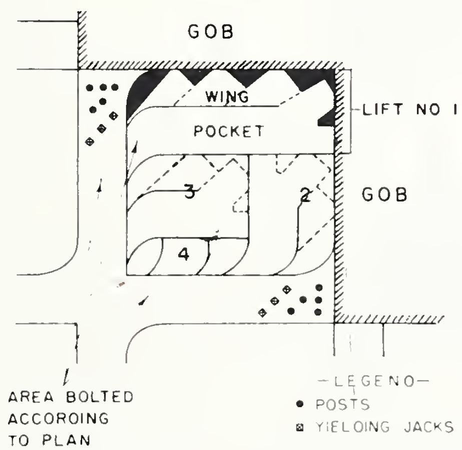


Fig. 10B - Detail sequence of extraction of a block of coal by the pocket-and-wing system.

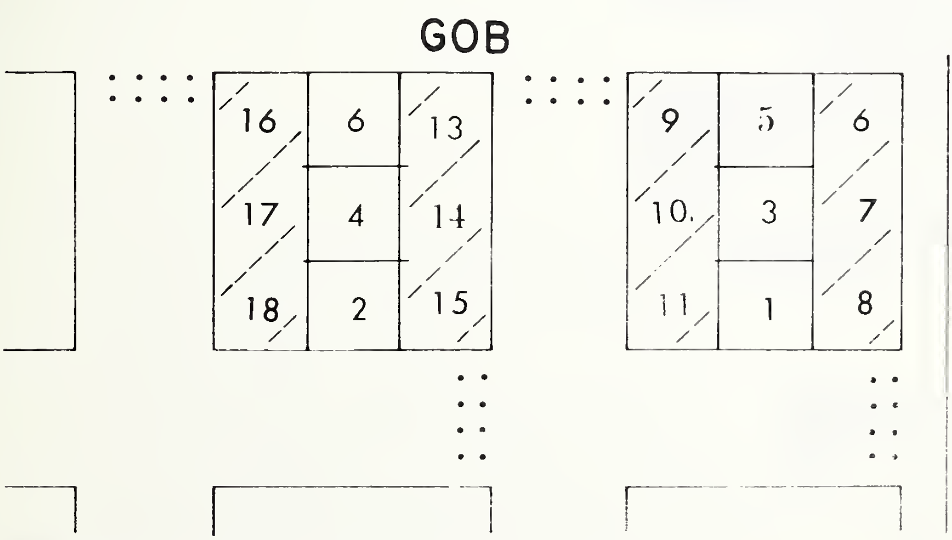


Fig. 10C - Detailed sequence of mining a pillar by continuous mining method

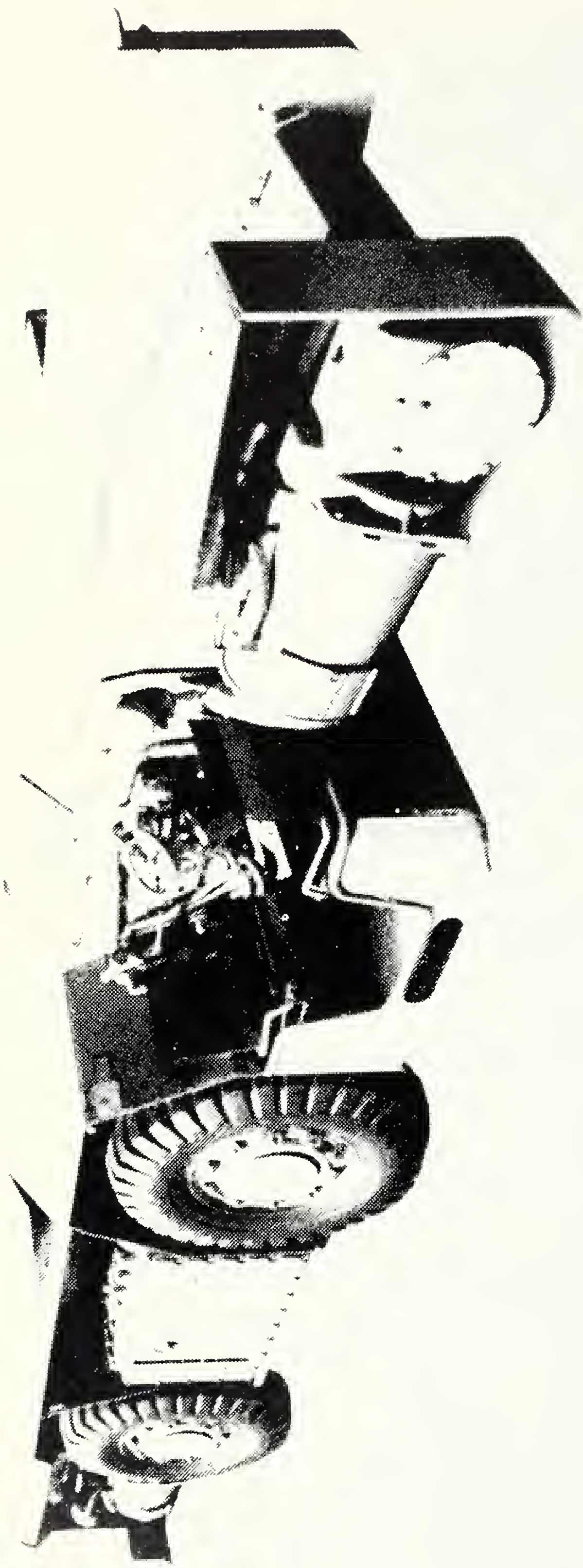


Fig. 11 - 10SC.

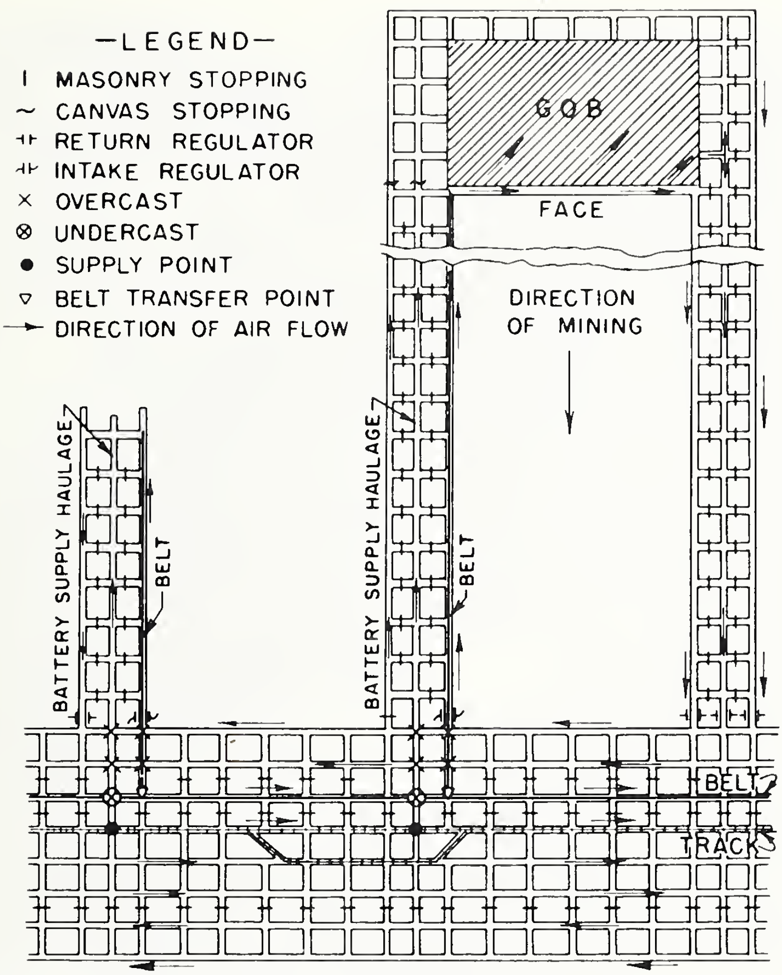


Fig. 12 - Plan for longwall development. Entries are driven by continuous miners.

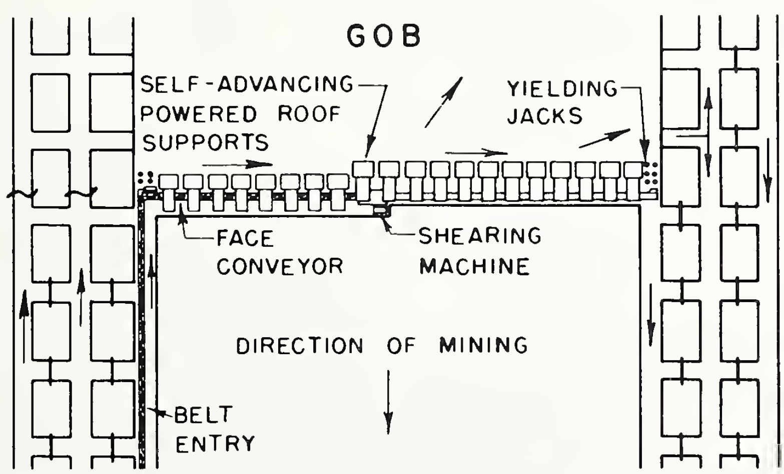


Fig. 13 - Plan of the longwall face shown in Fig. 12.

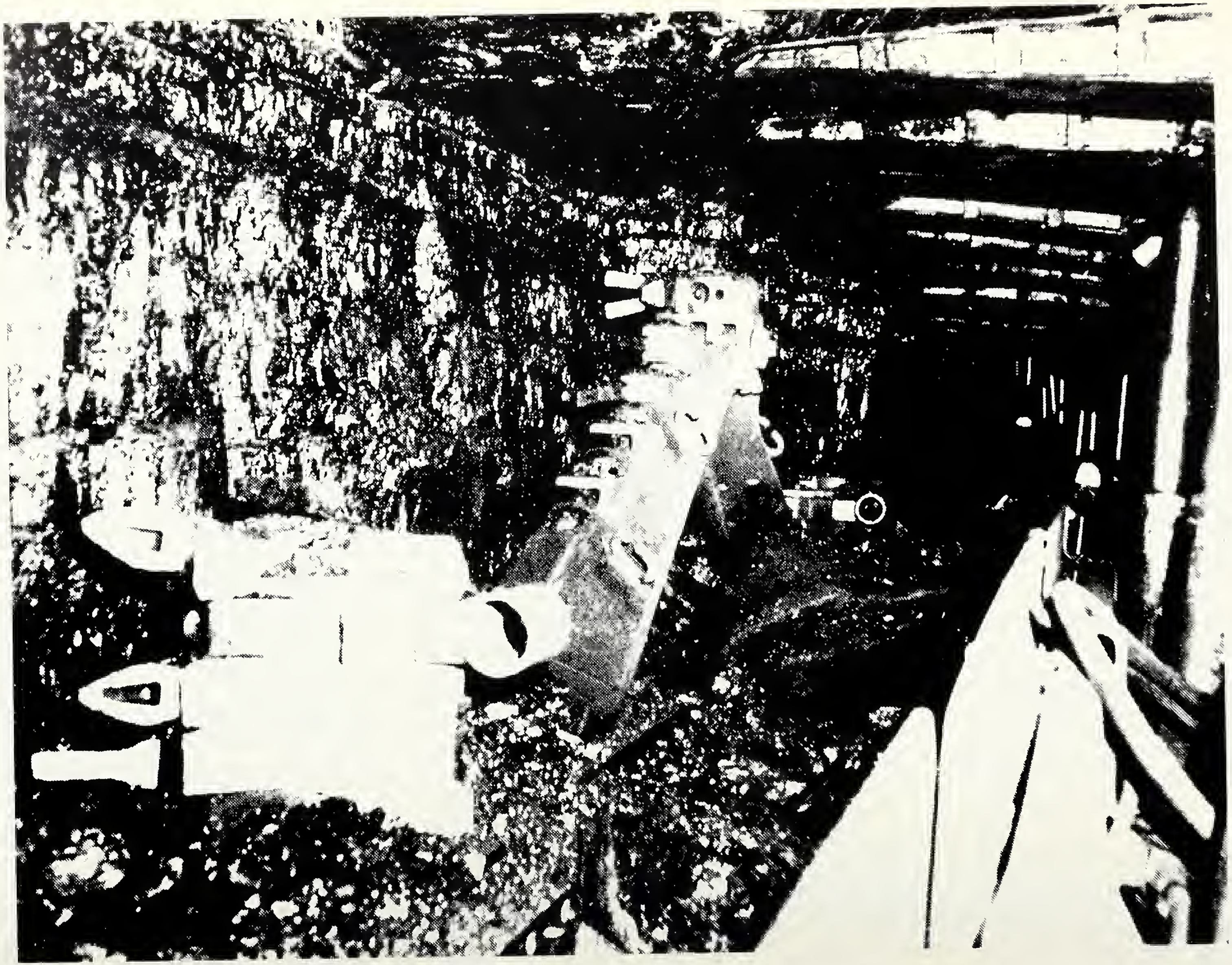


Fig. 14 - An A-frame plow, or planer, operating in a 54-in. coalbed in West Virginia. This type of plow mines in either direction.

Fig. 15 - A double-drum shearer-type longwall machine operating in a thick coalbed in West Virginia. Note drum in background cutting upper part of seam. Operator stands under protective beams of the chocks.

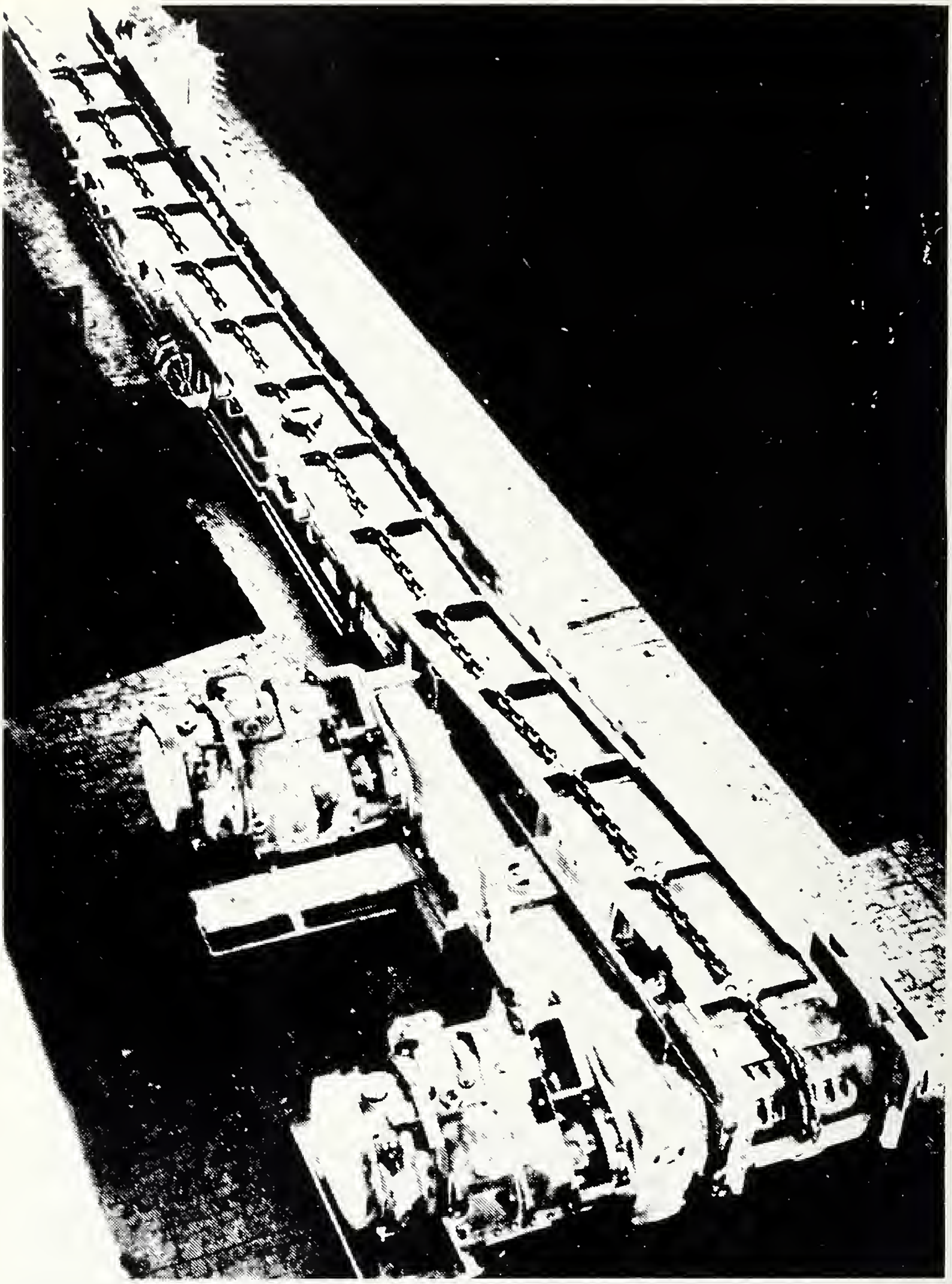
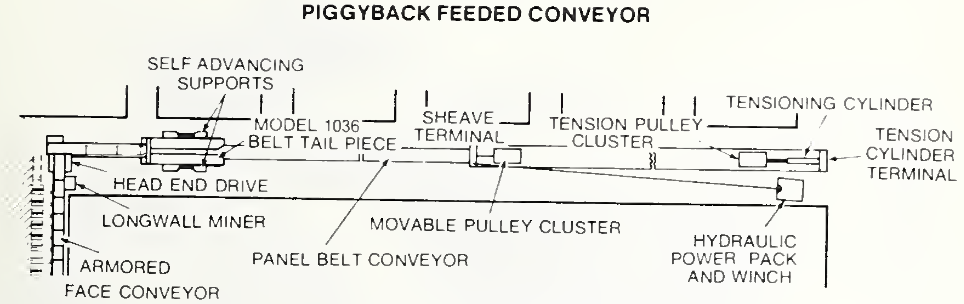
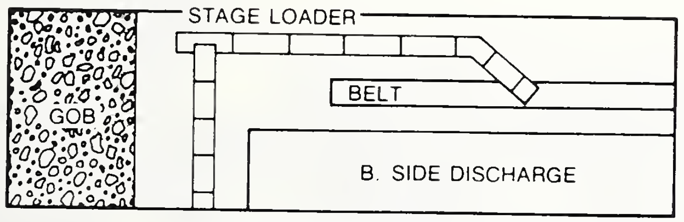


Fig. 16 - Drive end of a "panzer" longwall face conveyor, also shows plow mounting at upper end.



(a) Piggyback arrangement.



(b) Side tipping from stage loader.

Fig. 17 - Intermediate or stage conveyor arrangements.

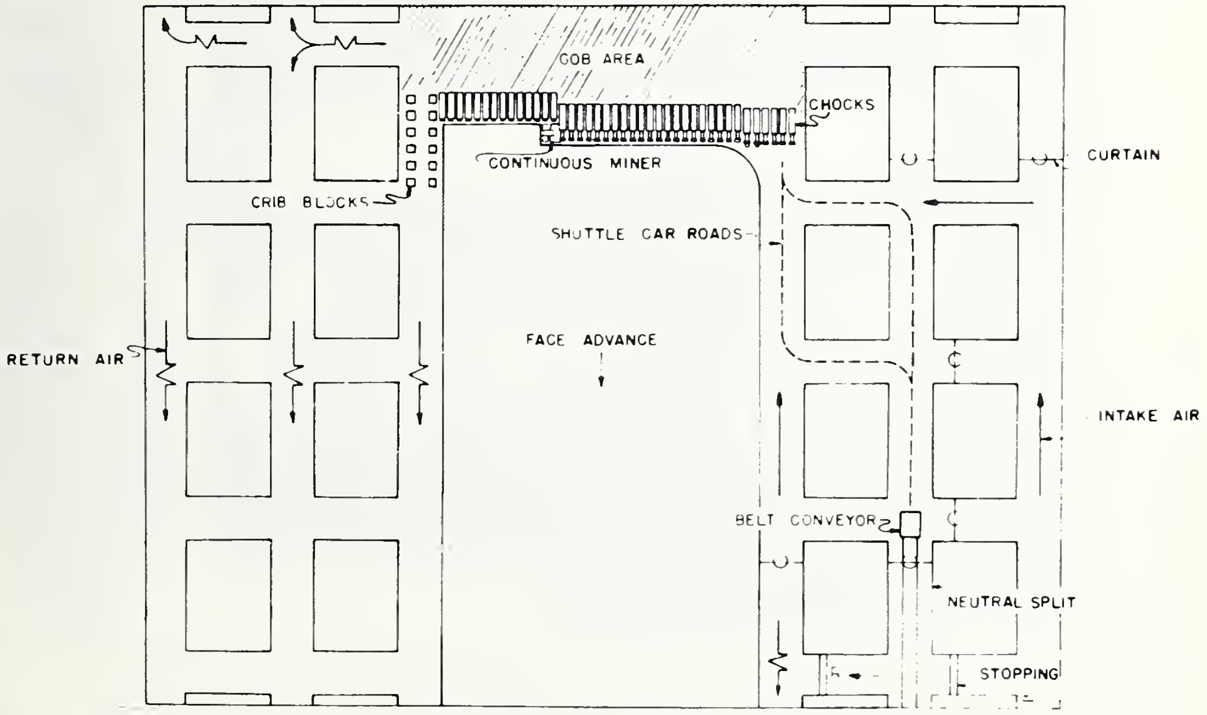


Fig. 18 - A short wall mining layout.

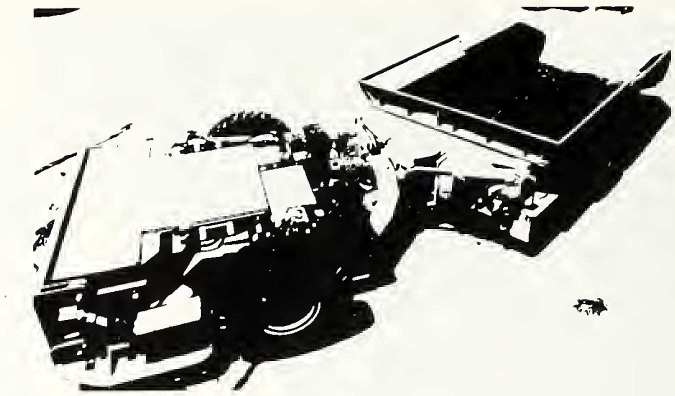


Fig. 19A - Ramcar.

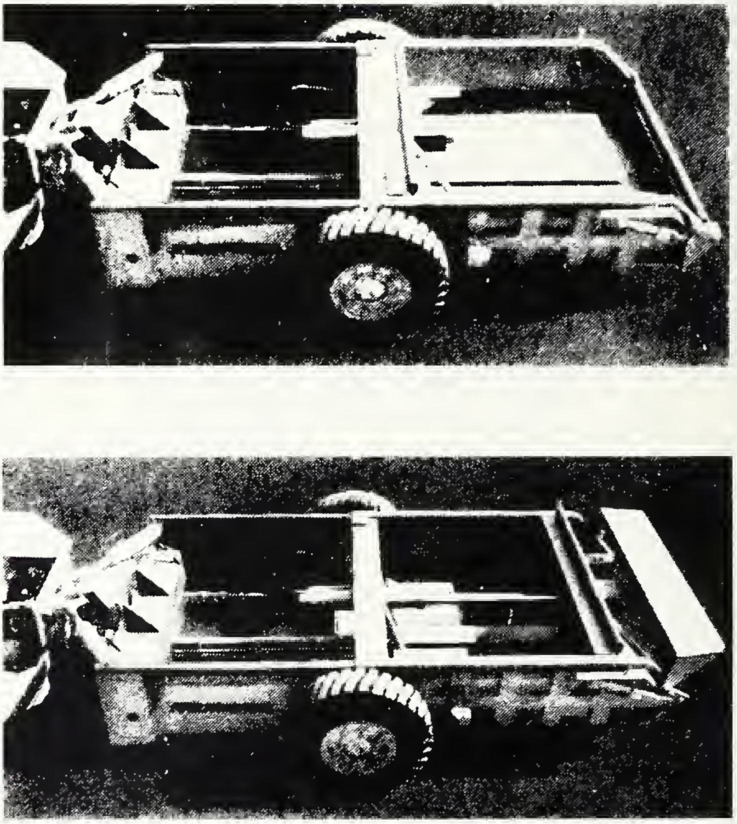


Fig. 19B - Operation of Ram-Dump Bed.

Fig. 20A - Tractor-Trailer Haulage Unit.

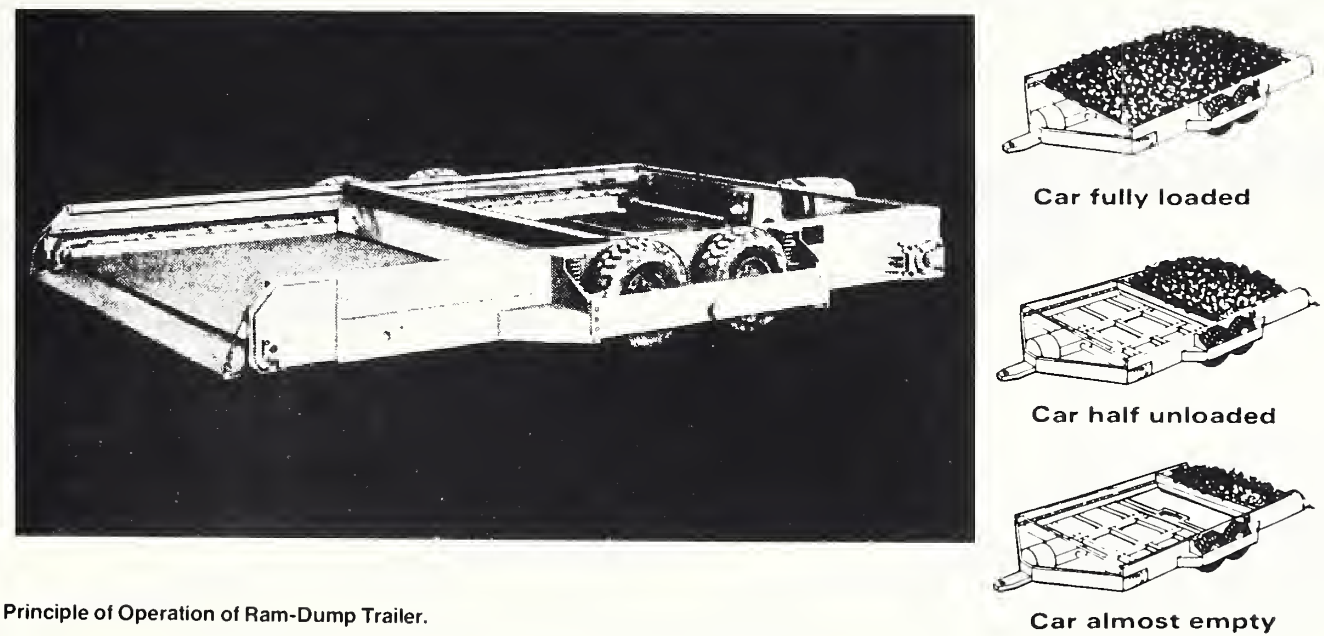


Fig. 20B - Principle of Operation of Ram-Dump Trailer.

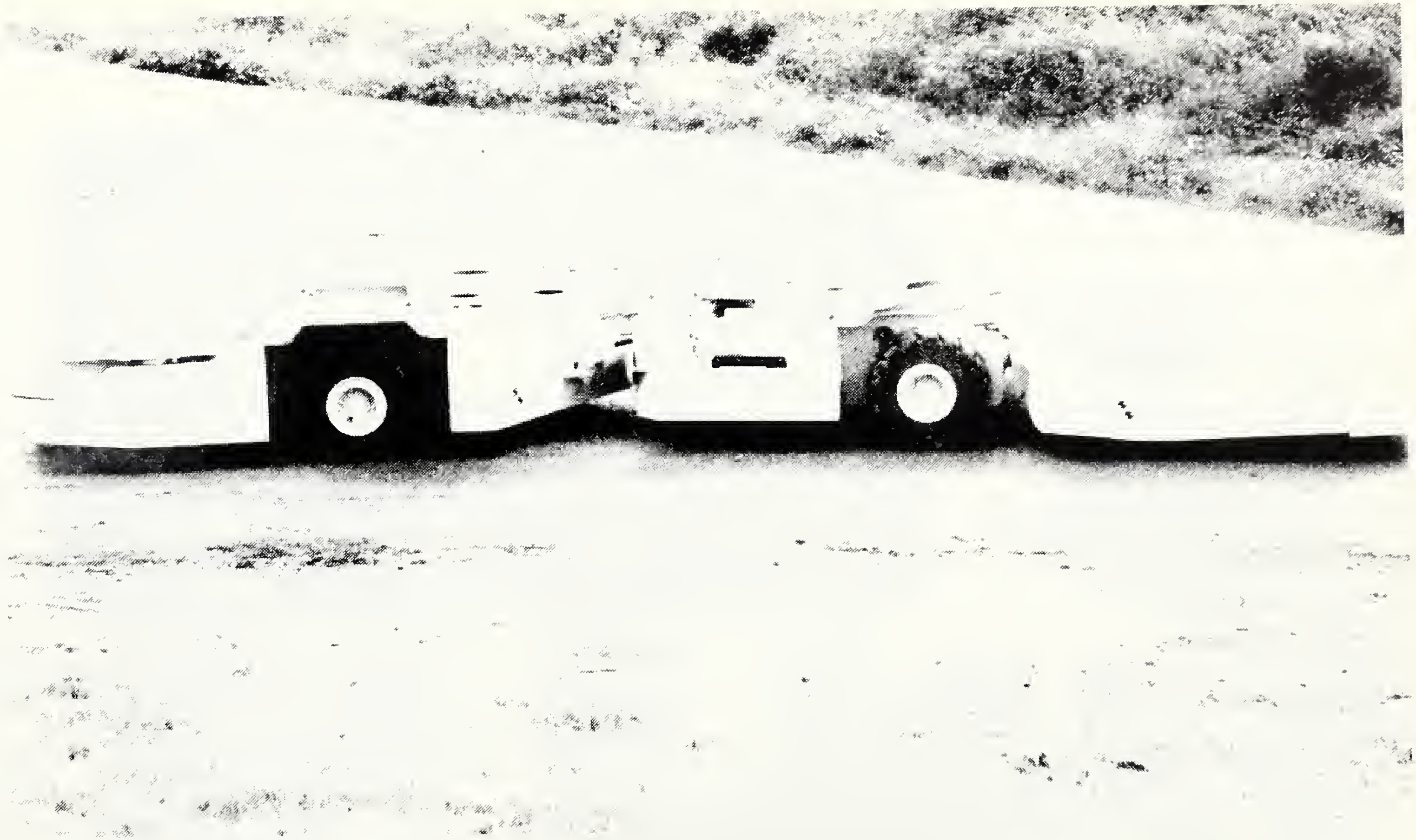


Fig. 21 - Underground front-end loader or scoop.

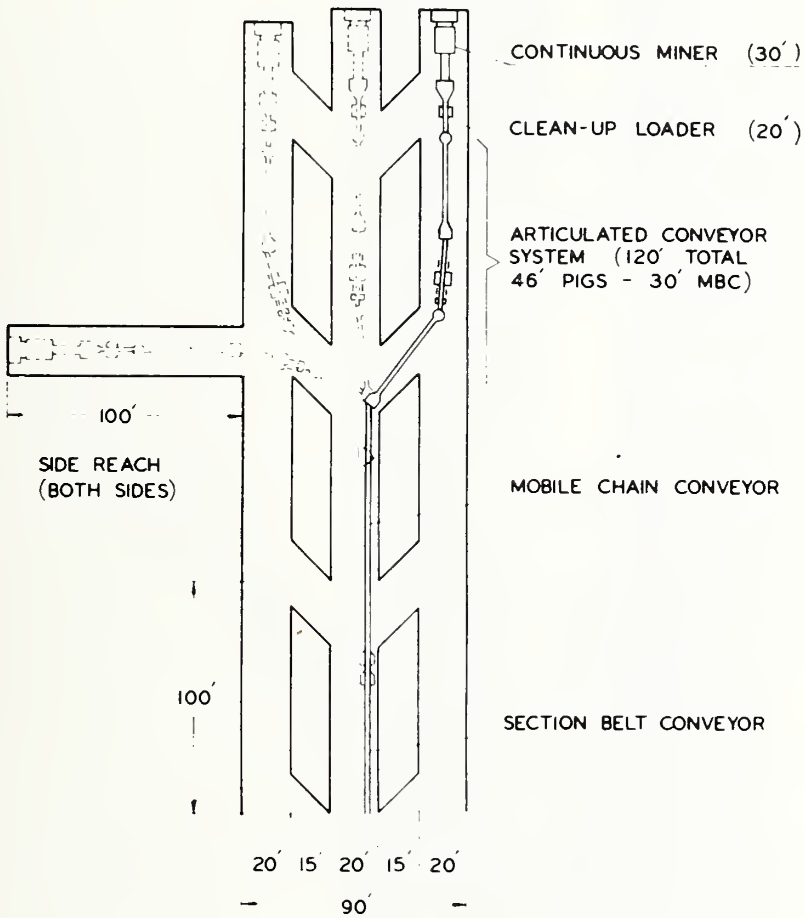


Fig. 22 - Continuous mining development using continuous face haulage, three-part train and loader, permitting complete extraction of panel approximately 300 ft. wide. Nine breakthroughs required for 990 ft. of entry and breakthrough drivage.

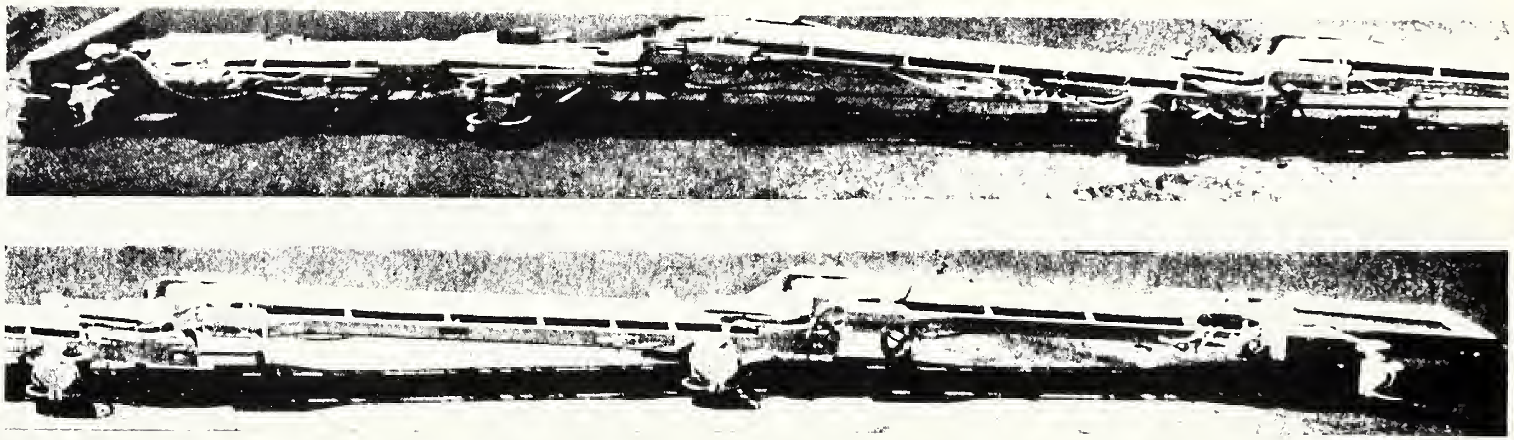


Fig. 23 - Cascading Conveyor System Extended.

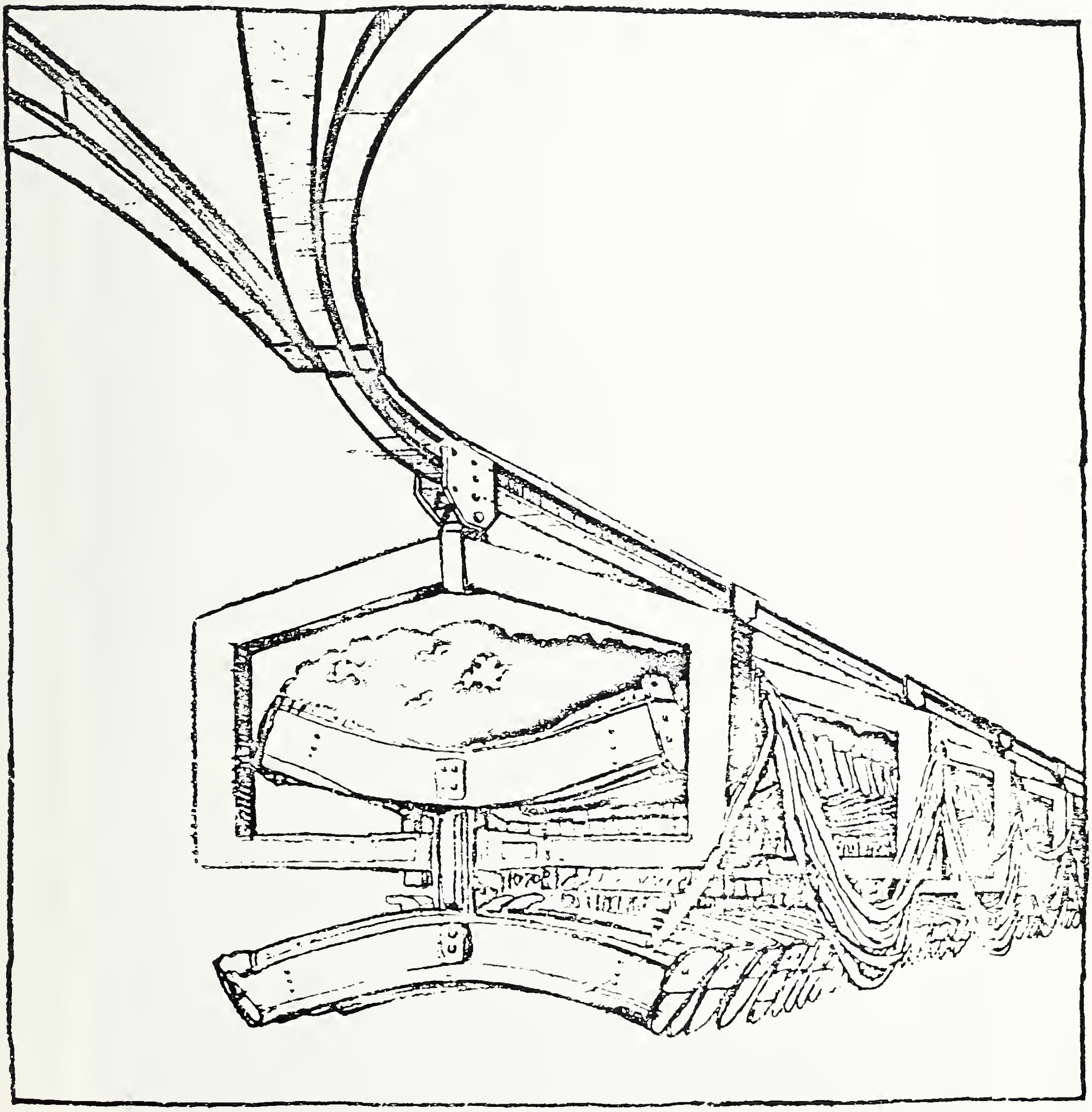


Fig. 24 Monorail Serpentix Conveyor

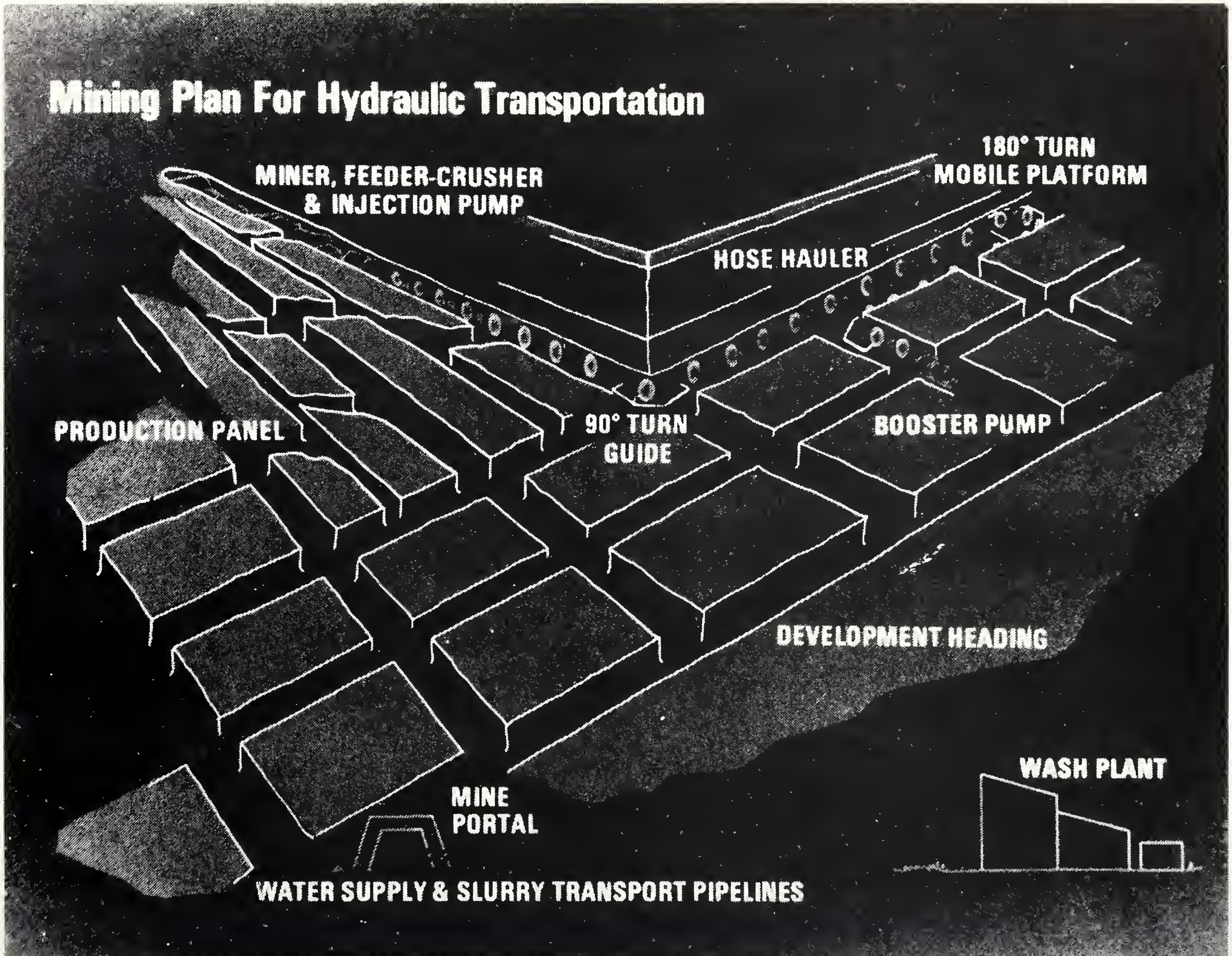


Fig. 25 - Hydraulic Transportation System with Flexible Hose Carrier.

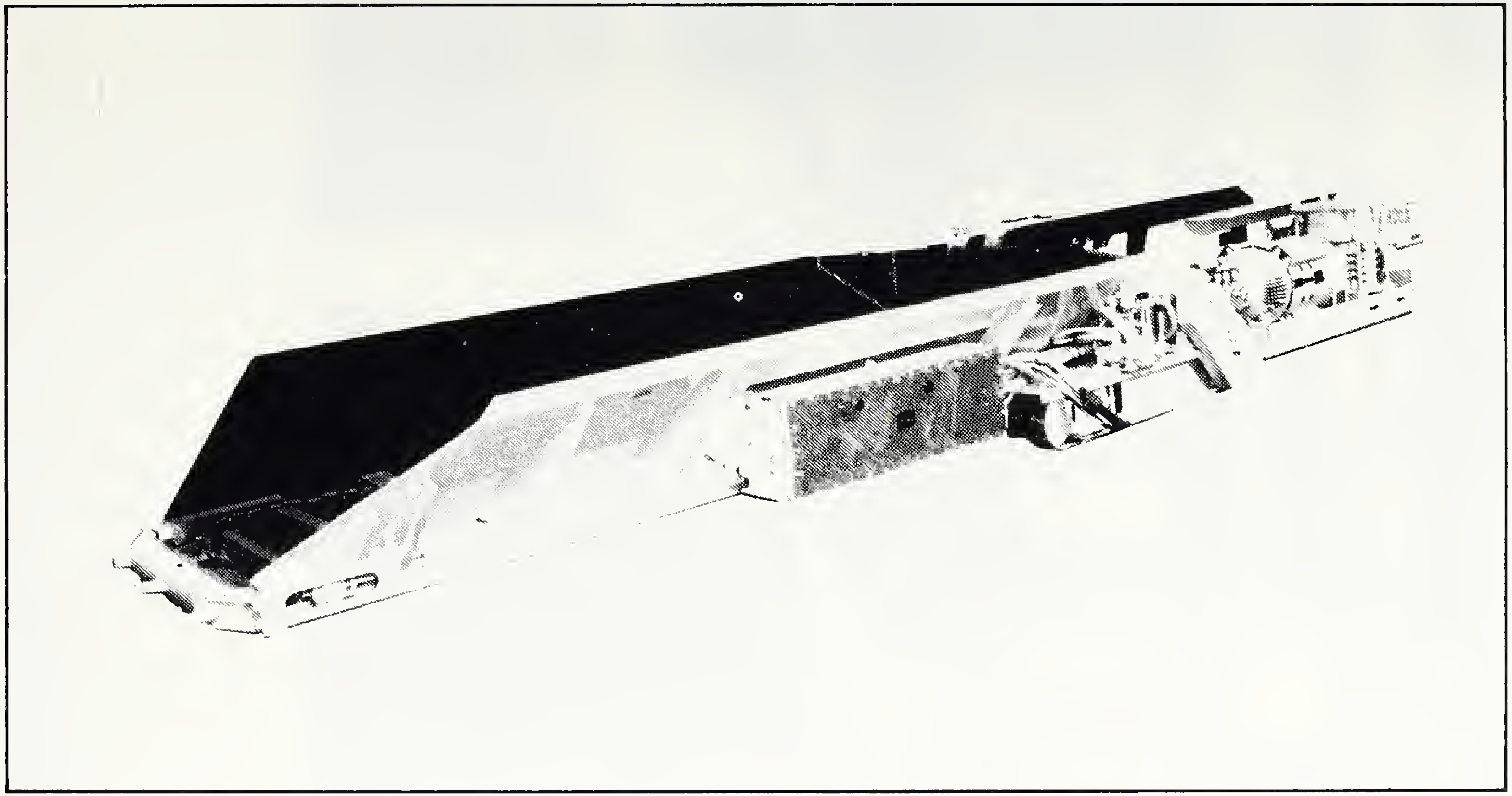


Fig. 26 - Crawler-mounted feeder breaker.

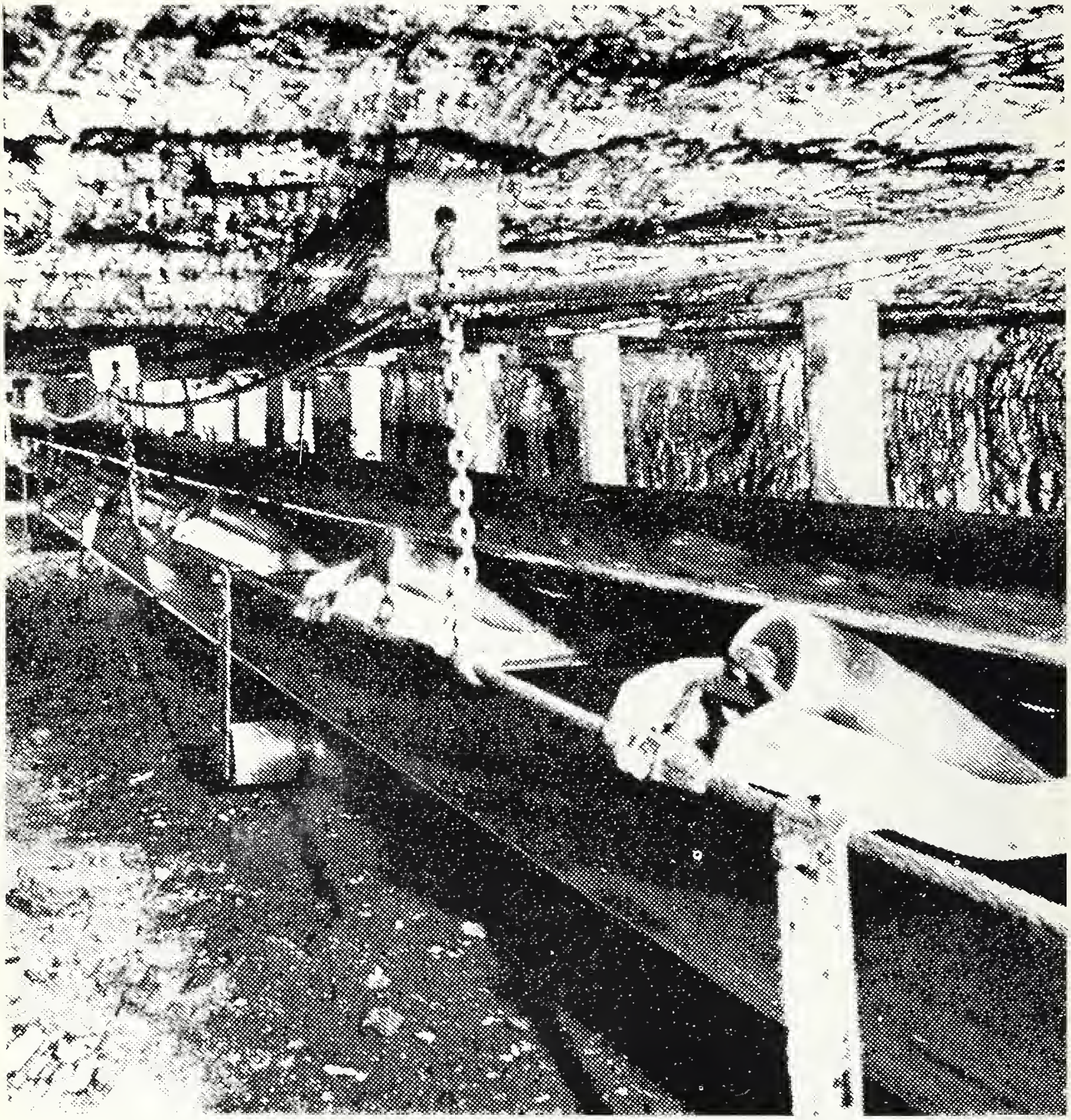


Fig. 27 - A chain and rope-supported underground belt conveyor.

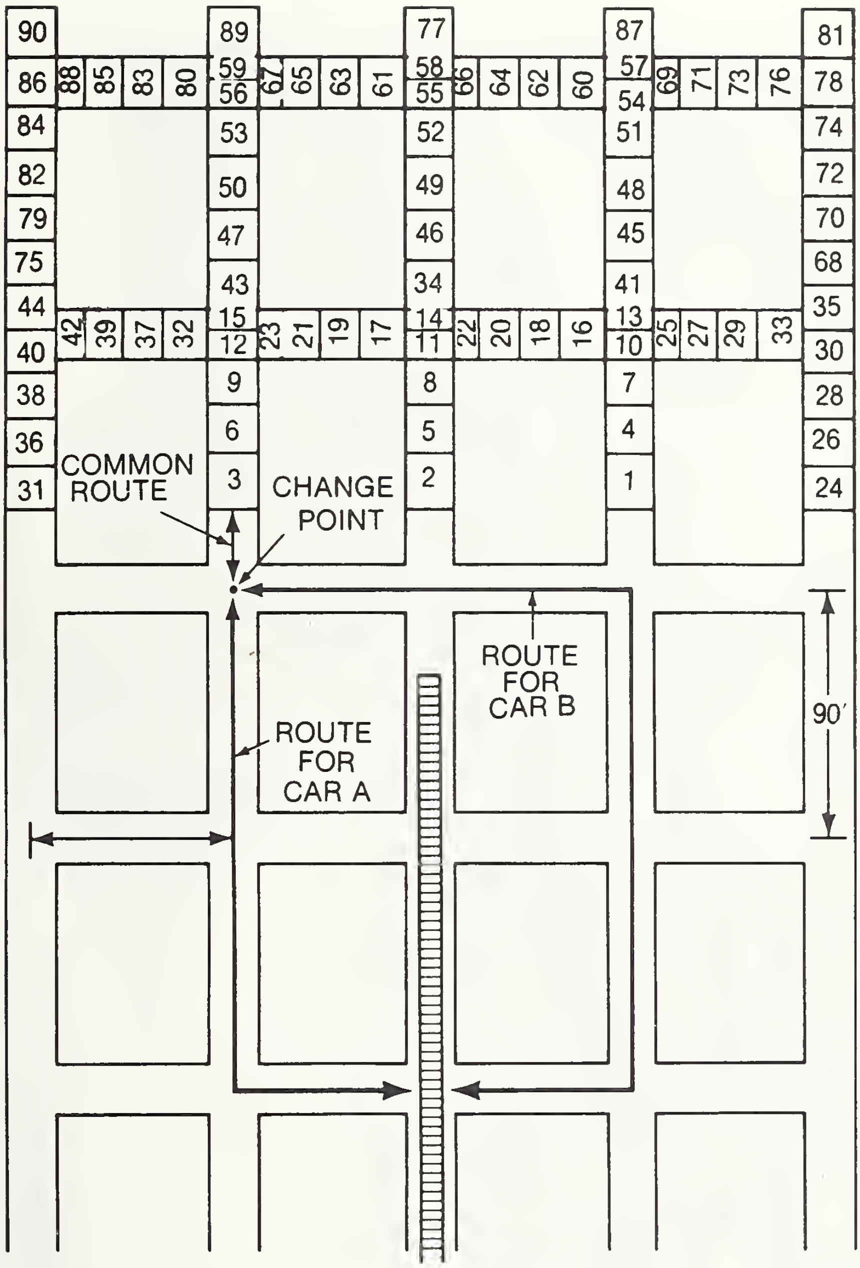


Fig. 28 - Loading directly into mine cars with the push-pull loading or single track system.

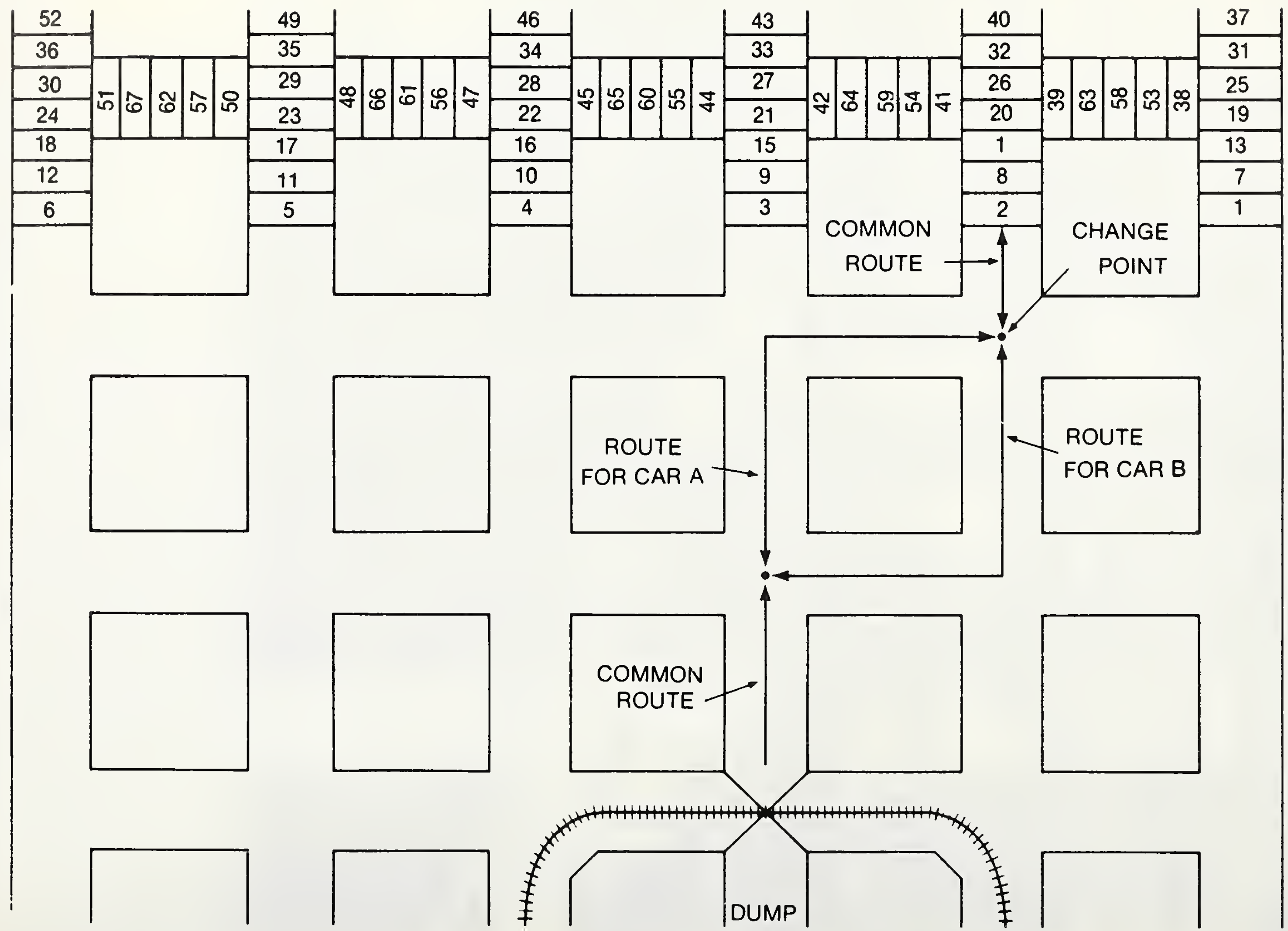


Fig. 29 - Loading directly into mine cars with the loop system.

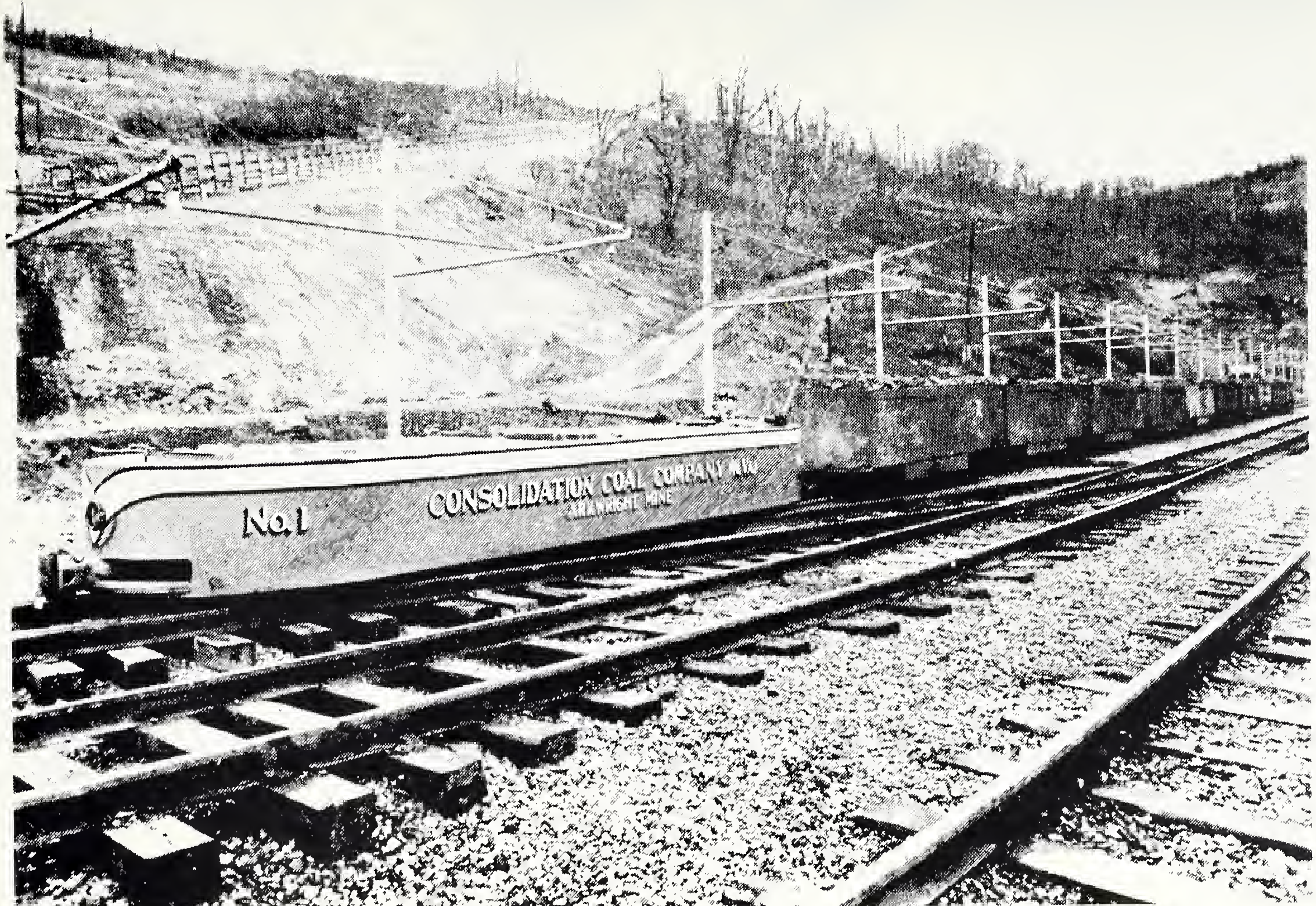


Fig. 30 - Main haulage locomotive of 50 tons weight, pulling a trip of large 8-wheel solid-body cars. Note the high quality construction of main-line construction of main-line track.

Fig. 31

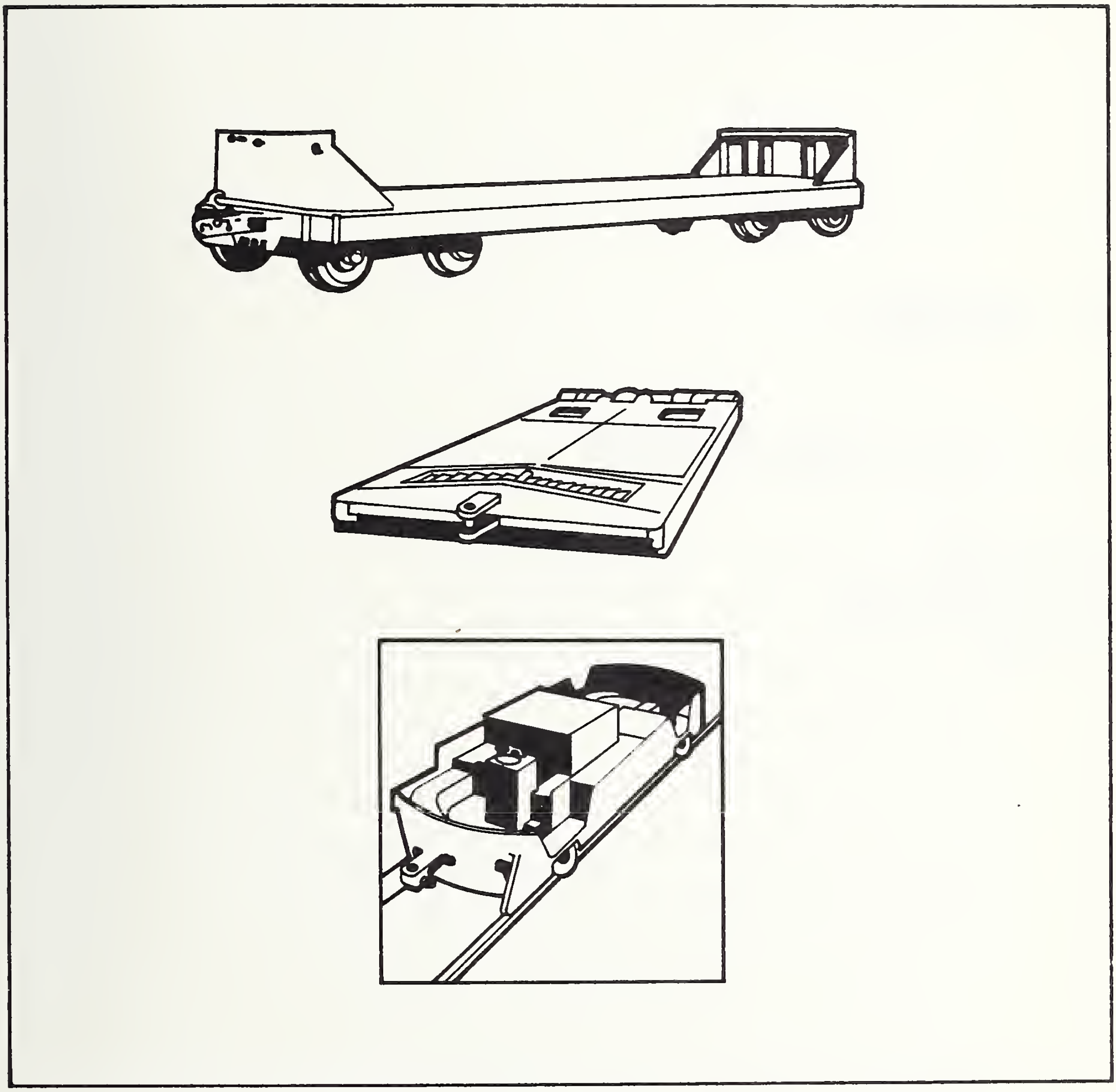


Fig. 32 - Utility cars for supplies, men and equipment.

PAPER 3

Materials Handling for Metal Mining

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WORKSHOP ON MATERIALS HANDLING FOR TUNNEL CONSTRUCTION

Keystone, Colorado August 3, 4, 5, 1977

MATERIALS HANDLING FOR METAL MINING

by

Gordon M. Miner

Vice President - Operations, Hecla Mining Company

Much can and has been said about the requirements of minerals for the next generation in order to keep up with the population growth and the improved standard of living for the populace. Various figures proclaim what the world may need in the way of mineral production by the year of 2000. These figures vary from a low of doubling today's annual output by year 2000 to a high of doubling every five years.

Today every American requires ± 40,000 pounds of minerals per year to maintain and improve his present standard of living. We recognize we consume almost 25% of the global supply of minerals while comprising only 5% of the population. It is the stated goal of many other nations to improve their standard of living and share in more of the wealth from Mother Earth. In order to do this, there has to be a vast improvement in the production of minerals.

Recent reports estimate that the amount of tunneling in industrial countries would increase 50% by the end of the decade and that sales of tunneling equipment would exceed $2 billion. Considerable development in tunneling technology has been directed

toward improving the actual advance rates at the face. The newer machines are capable of advancing in harder and more troublesome ground. In addition to improving tunneling machines, some improvement has been made in conventional drilling and blasting techniques. However, the major problems that seem to prevent further dynamic-improvements is the lack of developing a safe, adequate, rapidly-installed ground support system to control the opening in all situations and the ability to provide a muck handling system capable of handling the material from high-speed tunneling methods.

In my opening remarks, I have intended to convey to you that it appears we are entering the first phase of a minerals crisis. In addition, considerable capital and time has and is being assigned to tunneling improvements at the expense of neglecting the metal mining industry. I therefore consider it a privilege and a cherished opportunity to be a part of this workshop to discuss materials handling and give adequate consideration to the metal mining in-industry.

Every mining operation, whether it be open pit, underground metal mining or a high speed tunneling operation, is basically a problem in efficient materials handling. Indeed, in these days of skyrocketing costs and unstable metal markets, the ultimate success of many mining enterprises may well rest with innovative and effective materials handling techniques. The difference between a borderline operation and a successful, profitable venture may lie simply in the capability the operator has for moving the required equipment, men and supplies into the mine and product out of the mine.

In order to provide a brief and general look at the state of the art of materials handling in the mining industry, I felt we should look at the equipment now in use and have divided it into the following four major categories:

1. Mechanized equipment for driving headings.

2. Loading equipment.

3. Transport systems for ore and rock.

4. Transport systems for equipment, men and supplies.

1. Mechanized equipment for driving headings would include such typical items as the following:

a. The Jeffrey Heliminer, a manual or remotely controlled continuous miner.

b. The Westphalia ripping machine.

c. The Eimco 625 impactor.

d. The Ingersoll-Rand crawler boom-impactor.

e. The Alpine multi-head tunneler.

f. The Dosco continuous miner-loader.

g. The Goodman continuous borer-loader.

h. The Demag tunneling machine with shield.

i. Tunnel-boring equipment such as that developed by a) Atlas Copco, b) the Jarva tunnel borer, c) the Caldweld tunnel boring machine and many other similar machines.

j. Conventional track mounted or trackless jumbo drilling.

2. Loading equipment would include such machines as:

a. Articulated load-haul-dump equipment such as that built by Wagner, Eimco or Elmac Corporation.

b. Transloaders such as those built by Joy and Sanford-Day.

c. The Hagglunds loader.

d. Westphalia rake-type loader.

e. The Atlas-Copco auto loader.

f. Overshot mucking machines such as those made by Atlas-Copco, Eimco, Gardner-Denver and the Salzgitter throw shovel.

g. Slushers, both air and electric.

3. Transportation systems for ore and rock includes the following:

a. Track haulage with automated unit trains (diesel or electric, both underground and surface).

b. Pumped slurry lines for hydraulic transportation of minerals such as gilsonite, coal or phosphate, possibly combined with jet cutting.

c. Conveyors, including conventional belt conveyors and also the cable belt conveyor which has been installed for distances up to 9 miles. (Overland Coal Transportation Co., Morgan-Field, Ky.)

d. Trainloaders such as the a) Salzgitter Bunkertrain, b) the Hagglunds shuttletrain, c) the Sandford-Day slusher train and c) the Coeur d'Alene's Company trainloader.

e. a) Overhead monorail systems and b) mounted independently powered monorail systems as built by Becorit.

f. Specialized conveyors such as those made by a) Dashaveyor (the automated conveyor train), b) Serpentex and c) Secam.

g. Aerial tramways.

h. Conventional track or trackless haulage.

i. Pneumatic stowing and conveying.

j. Hydraulic sandfill or backfill in pipelines.

k. Marconoflo loading and unloading systems.

l. Pneumatic capsule pipeline systems, such as those now under study in the U. K.

4. Transport systems for equipment, men and supplies would include:

a. Forklifts.

b. Grab jaw trucks for packaged materials.

c. Specialized supply and personnel vehicles, tracked or trackles

d. Man conveyors (chair lifts).

e. Monorails

I doubt if many people other than those of us associated with the noncoal mining industry are aware that a high percentage of this equipment is made for driving large headings or roadways with very little of the equipment applicable to production. In recent years, there have been advances in technology and equipment used in extracting ore from underground mines using some type of a caving system and in open pits, but there has been little change

in equipment used in smaller, narrow-vein type mines during the last 40 years.

The ultimate solution for the industry is a total integrated mining machine which will excavate the rock, provide material removal from the heading, and concurrently place permanent ground support. If the mining industry in the USA is going to survive, we must have improved productivity and lower costs through better mining and material handling methods. Without improvements, the United States will become more dependent on foreign sources for out mineral requirements.

I felt it would be of interest and informative to the group if I spent a few minutes on some specifics related to the Coeur d'Alene Mining District.

The most unique feature of these mines is their extreme depth. The ore bodies are in narrow, near-vertical fissure vein replacement structures requiring selective mining by cut and filling with hydraulic classified sands. Folding and bending of the original sedimentary beds has resulted in the quartzite host rocks standing near vertical so that a steeply dipping vein may stay in the same favorable horizon to great depths. Several of the district mines are developing and mining at 7000 to 8000-foot depths below the surface and in many instances, the main hoisting shaft lies at the end of a 1 to 2 mile long haulage adit.

Material handling in our Coeur d'Alene district mines involves not only efficiently removing ore and waste from these great depths,

but the transportation of men, supplies and equipment in and out of the workings. The general mining or materials handling procedure consists of removing the ore from the freshly blasted face and transporting it to a holding chute. From there it is moved to the main shaft area via rail and dumped into shaft pockets, from which it is hoisted to surface and dumped into a surge bin and finally it is moved via rail or conveyor belt to the concentrator, if it's ore, and to the waste dump if it's waste.

Typically, muck will be transported about 3½ to 4 miles even in the deepest Coeur d'Alene mines, but during this trip it may be handled as many as seven times and change flow six or seven times.

The transportation problem is further complicated by the fact that as these mines have continued deeper, ground pressures have increased immensely, which dictates the development of relatively small cross-sectional openings in both horizontal headings and vertical or inclined shafts. These small openings have a great influence on the size of any mining machinery, including materials handling equipment, which can be used underground.

Surface adits can be sized to accommodate the larger pieces; however, it is difficult and often only after much disassembly that equipment can be lowered in cages that are built to fit inside a shaft which typically measures 4 feet by 5½ feet.

Without doubt, the biggest controlling factor in the speed and efficiency of the material handling system is the rate of hoisting achieved in our shafts.

There are other problems that arise in a mining situation. At times we've heard the criticism that something was apparently under designed when a component of the mining cycle fails to function as well as others do and appears to be a bottleneck. This is not necessarily the case. Historical factors have to be considered.

Take, for example, the case of our Lucky Friday mine:

The mine was developed by an individual who had faith from what he saw in a small surface outcrop. The original small vertical shaft was sunk to a depth of about 2,000 feet over a considerable time span before he mined ores of any consequence.

After it appeared there would be sufficient mineralization available to produce a relatively small constant tonnage, a new and larger shaft was started. The facility was believed to be of adequate size to mine to a depth of about 4000 feet, if the ore continued. It now appears the shaft will be used to about the 5000 level and then an offset winze will be needed to provide a means of mining the ores that exist below that level.

The capital cost of duplicating these openings would be prohibitive, so in most cases many of the size restrictions which were the responsibility of the early timers and were adequate for their needs cannot now afford to be replaced. Therefore, these physical handicaps must be offset by increased productivity, by new equipment and methods, in conjunction with efforts to discover more new ore bodies within the mine to replace the ores presently being extracted.

It is my intent to illustrate by my remarks concerning the Lucky Friday mine that many of the problems that seem to exist are not necessarily the results of poor planning.

Some of the typical mechanized equipment for driving headings in the Coeur d'Alene district are as follows:

1. Track mounted jumbos or, in some cases, jackleg drills.

2. Loading equipment.

    a. Overshot air-operated muckers.

    b. Train loaders or slusher trains.

    c. One cubic yard, electro-hydraulic LHD units.

    d. The Atlas-Copco 310 or T-2GH rubber tired, air operated LHD.

    e. Shaft mucking equipment such as the Coeur d'Alene clam shell, the Cryderman mucking machines or the Riddell shaft mucking machine.

3. Transportation systems for ore and rock include:

    a. Battery locomotives and 60-cu. ft. cars on the levels.

    b. Main line haulages with electrified trolley or diesel locomotives with 6-8 tons cars and 100-ton trains.

c. Conventional conveyors.

d. Hydraulic sandfill, both pumps and gravity fed.

e. Vertical and inclined hoisting shafts with up to 20-ton payloads traveling at speeds up to 2000 fpm.

4. Transportation for men and materials include:

a. Horizontal haulage using diesel or battery locomotives with mancoaches and material cars.

b. Vertical and inclined hoisting in man and material cages.

c. Loading and unloading of materials from shaft cages using forklifts, grab jaw trucks, air tuggers and monorails with hoists.

I would now like to address the following question: "What is the problem regarding materials handling?", it appears to be basically a problem of communication. The various industries have much technology in this area, yet there is very little exchange of information. Further, a full exchange of technology between the construction-tunneling industry and the mining industry is lacking. Joe Sperry does an excellent job in addressing this subject with his article in "Special Report to the Transportation Research Board".

It is interesting to view differences in approaches to solving the problem between construction tunnel driving, open pit mining and underground mining.

Civil engineers are interested in a tunnel construction as a reasonable facsimile of the client's requirement and will design it to fit the client's needs taking into consideration safety, cost, selection of method, select the equipment, explore the site, do investigative drilling, make changes in sites if possible and complete the construction. Therefore, the muck handling system is an integrated component of the total system.

In open pit mining, much the same occurs with the exception that the location is absolutely fixed, but a total system can be designed which does include materials handling.

In underground mining, tunnels are not an end in themselves, but are part of the total development of a mine. Tunnels may be designed to remain as permanent openings or may be abandoned after varying periods of time.

Tunnels in a mine may vary greatly as to size, ground conditions, and alignment. Therefore, design for underground equipment must consider simplicity and versatility.

Usually, mines are in a constant changing scene of production The advance rate of development headings within a total designed mine will be conditioned by the capacity of the mine to dispose of the muck. What I'm saying is that materials handling

is the most important component of any underground mining system and other components have to be designed around it.

The mining industry has a great deal of information on the maintenance and operation of LHD equipment which should be useful to other areas of the industry. Most improvements in the design of this equipment has probably come from our industry.

It has for example, been possible to utilize the knowledge gained in high speed tunnel boring for driving development headings in the mining industry. However, much more exchange of information is vital for the continued growth of all facets of tunneling. We certainly are not blaming the coal miners or construction people for this failure in communications because we know about the lack of communications even amongst members of our own industry.

Mine operators and mining contractors know what their individual problems are, but they are not in a good position to solve them, because they cannot justify the time and expense. Development of new equipment is a high risk, high investment business with long, costly development time required and much trial and error.

The equipment manufacturer is in a better position to develop new equipment providing he receives input from those knowledgeable in the mining industry as to what the problems are, what equipment is needed, and whether or not that equipment would have the possibility of developing a market sufficient to provide a good return on investment.

We understand though that some of these projects may be too large to suggest that one manufacturer alone bear all of the risks. I am not talking about someone developing a new faster hoist or a higher capacity conveyor. I am suggesting the development of a new concept., that would require the cooperation of all phases of industry and government, working in much better harmony than they do now.

At the present time a great deal of research and development work is being done in this country on a contract basis for the U.S.B.M. and others. These research projects have yielded some results on occasion but these have not been commensurate with the costs involved. Unfortunately many of the contracts have been let to firms with excellent credentials who in turn have provided less than first-class supervision to impractical engineers. All too often such studies have resulted in a report which describes current industry practice, recognizes the problem areas, but offers no solutions.

In the field of research, the performance and capability of the South African Chamber of Mines has always been impressive. This organization is a 3-tiered structure topped by the Transvaal and Orange Free State Chamber of Mines. The Chamber of Mines is a non-profit organization sponsored by the financial companies or mining houses and the mines themselves. The second echelon consists of the finance companies or mining houses. There are seven major houses, each of which may operate as many as 20 mines. These companies command large financial resources and maintain extensive consulting services covering research in all areas concerning

the mining and metallurgical industry, including financial and administrative services. The results of this research are available to all the associated companies. The third level of this 3-tiered system is the individual mines themselves. The function of the mine is just as it is anywhere else in the world - to mine a specific ore body at a profit.

Thus, a well financed research organization composed of the best people available, studies the problems of the mining industry, provides solutions and makes them available to all mine operators in the country.

Unfortunately no similar organization to the S.A. Chamber of Mines exists in our country but I believe that our research efforts can be improved by drawing from their experience.

In discussing research with some of my colleagues, it has also been suggested that maybe we could get some long term research benefits if the government would grant long term support to certain mining and civil engineering schools so they could obtain improved capabilities. This not only would improve the facilities at the university but attract industry leaders to work with and teach our students and improve their interest and capabilities . I do not completely agree with the concept but do believe it warrants some study.

I believe some of the basic problems related to the metal mining industry hampers the development of new equipment for the automation and modernization of our mines.

Although some progress has been made in the search for more efficient methods of metal mining, much of our technology is the same as it was 50 years ago. However, some mines are using L.H.D. units of varying capacities, larger loaders are employed at some large underground operations, mechanical raise boring has become quite common at most underground operations where raises are driven, and one or two companies have used, or are currently using, some type of tunnel boring equipment for developing horizontal openings.

Many of our operations still employ conventional methods which include drilling and blasting, slushing, over shot muckers, rail mounted equipment and hoisting. Yes, the equipment has improved. Penetration rates for drilling are better, slushers are larger and faster and hoists have been semi-automated but the basic operation is much the same as it was many years ago.

When we try to solve a problem with mechanization, we must try to reach two basic objectives:

1. Improve productivity.

2. Improve the human aspect in mining.

Improving productivity has the obvious advantage of better manpower utilization and it is the only hope to keep the inflationary spiral at a reasonable level. In addition to that

it will contribute to improved conditions throughout the mine. I talked earlier about the fact that in mining, several levels or a wide area of mining has to be in operation at the same time in order to meet production goals. Significant improvements in production or development rates would mean a reduction in the number of these working areas and allow us to concentrate our efforts. This would lead to a better ground support, closer supervision, improved safety and of course lower costs.

Mining is probably more labor related than any other industry. For years we enjoyed an unlimited supply of labor. It was a job that was easily learned, it did not require any formal education and the pay was much higher than for other industries.

A few years ago we saw much of this change. Management of mining attempted and to a degree has been successful in keeping labor cost increases at reasonable levels. This is of course dictated by the fact that the mines are dependent upon the selling price of their product and we all know how that can fluctuate, unfortunately not always upward, in fact the price of silver and gold were artificially fixed at a very low level for many years. Contrast this with other industry where the rapidly increasing costs of labor is passed on to the consumer and you can see why it has become more difficult to attract miners merely on the strength of good pay.

The mining industry has had unfavorable press over the past few years, particularly in the areas of environmental matters and safety and this has certainly had an influence on young men considering mining as a career.

We know that it has become more important to consider values other than money and company benefits when considering jobs. Values such as increased job responsibilities, importance of the job, work enrichment, etc.

A man who has to muck a ditch using a shovel and pick may regard the work as degrading whereas a man who runs a backhoe will accomplish the same work in a lot less time and the operator will regard himself as a machine operator rather than a ditch digger. Another example is impact hammer operator at grizzly rather than a plain boulder breaker using a double jack. So when we work towards improving productivity we also work towards better use of available manpower and attract new people.

The improvement of materials-handling equipment for underground mining operations must also take into consideration the following problems. Not all of these are related to every mine of course.

Many mines are hot, in fact rock temperatures in some cases are so high that giant refrigeration units have to be used in order to cool the working area sufficiently so that people can work there. Machines that require large amounts

of power obviously will add to the problem because of heat generation and additional cooling may be required. Machines may even have to be built to incorporate portable coolers. The heat generated will eventually have to be dumped somewhere.

Humidity and water is often a problem in mines. We have experienced a lot of difficulty keeping electrical components of any equipment dry underground. Design of new equipment should consider this problem while still allowing for routine maintenance.

Corrosion and chemical reaction underground are sometimes severe. The stories about ferrous parts of machines being eaten up in some copper mines in a matter of months are not exagerated. The warm humid climate accelerates corrosion and some components of new machinery may have to be made of special alloys.

In deep mines, rock pressures may be immense. This has the effect of complicating simple ideas such as handling material in pipelines, which are installed in boreholes.

Many veins are formed in a hard abrasive rock. In the Coeur d'Alene mining region, for example, the quartzite may be 10-20 times as hard as coal and it would be foolish to attempt to employ machines that have proven successful only in the coal fields.

Earlier I discussed the problem of small openings access into mines, particularly deep ones. Equipment for these mines must be so designed so that they will either fit into the available openings or easily disassemble into units that can be handled. The designs must be simple yet rugged.

Ventilation of underground mines takes a lot of planning. Much has been done in the past few years in the determination of sufficient air flows and the use of refrigeration and cooling to improve the underground environment and make it suitable for people to work. The design of any equipment will have to take this into consideration. For example, the use of diesel powered equipment may be prohibited in some underground mines because of insufficient air flows.

In many instances mineral being mined are in narrow veins. Mining these narrow veins often means extracting rock in widths greater than the widths of the mineral and dilution results. To keep dilution at acceptable levels, mining should take place at widths as low as practicable. However, the widths of these veins change and any equipment should be versatile enough to generally handle these changes in mining widths.

In a mine, production may take place simultaneously on several levels if the vein is vertical or over a long face length if the vein is flat. To allow the rapid mining of several areas simultaneously, any equipment developed for underground must be versatile and maneuverable so as to reduce

capital outlay for several pieces of the same equipment that would be utilized only for short periods of time and to maintain high productivity.

It is no longer sufficient to build a new piece of equipment, place it in a working environment, discover perhaps after an accident, that there are some hazards associated with the machinery, then try to engineer around those hazards with spagetti wiring or apply home rules and regulations for your employees to adhere to.

Safety must be an integral part of the equipment design and all government safety standards plus the conditions under which the equipment will operate must be considered from a safety standpoint, when the machine is built.

What of the future? There is a story about a man who, when asked what his one wish would be, told the gods that he wanted eternal life. Many years later - sick, old and weak, he asked that he should die telling the gods that he realized too late his folly in asking for everlasing life when he should have asked to remain forever young.

There is a real challenge for the future. We should embark on a program of research and development but the decision to embark on such a program does not necessarily lead to results unless the decision is backed-up by an understanding and willingness to have moderate patience and not be too demanding for immediate results.

Government must formulate or adhere to the present minerals policy stating its goals for the future including budgeting for research and development.

The development of technology in underground metal mining is a challenge to all persons involved in the minerals industry. Mining companies, equipment manufacturers, research laboratories and government must all work much closer together, as suggested earlier, achieve results that will continue to provide the needed minerals and an attractive way of life for future generations.

We must set goals and then act on these objectives so that our industry can look forward to a long life, and what's more important, that it can remain forever young.

Hopefully, this meeting will provide the opportunity for a much needed vehicle for communication between Mining, Construction, and Tunneling. We will be better informed and probably have much better insight on the problems each of us has in order to meet the forthcoming challenges for survival. I expect we will all develop a better sense of priority and will be surprised if we do not find our problems more common to each other than expected.

Thank you for the opportunity to address this workshop.

The photographs initially submitted with this paper have been deleted due to the difficulty in obtaining copyright approvals.

PAPER 4

Materials Handling for Underground Construction

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INTRODUCTION AND THEME

The Department of Transportation's 1976 publication, "Tunneling, the State of the Industry", projected that over 146 miles of tunnel would be built in this country in the next eight years, with over a third of this in the rapid transit systems. This projection represents approximately 7.5 million cubic yards of excavation. President Carter's recent cutbacks notwithstanding, demand for tunneling is high and continuing. Coupled with the acceptability of today's generation of sophisticated boring machines and excavators, there is need for sophisticated materials handling methods. I feel as though it is somewhat redundant in my trying to define the state of the art to persons such as yourselves, who are tunnel people and suppliers to tunnel people, persons at the vanguard of the state of the art. I do not think it is necessary to get down to the fine details of how each system works, or to rehash old arguments about the relative economics of rail or rubber tire haulage. When there is a question about which way to go, the final word is often as much a result of personal preference and equipment availability, as it is a study of the objective economics.

One perspective on this subject is that the purchase, installation, and operation of a materials handling system tends to be in the range of 15% to 20% of the direct cost of the tunnel excavation. Tunneling and underground construction costs are spiraling with inflation, and the cost of handling the materials is not a negligible portion. The majority of tunnels in this country are built with public money, and any savings that can be introduced will benefit the public.

Tunneling and underground construction have been proposed for underground storage of natural gas and petroleum products, to be used as a buffer against temporary slowdowns in availability. Tunneling plays an

important role in power and energy development, both hydroelectric and nuclear. Tunneling is often the method of construction that has the lowest environmental impact on urban or congested areas and on transportation or water systems through mountains or ecologically sensitive areas. Even in a period when building trades have been severely depressed, tunneling demand has been steady.

One of the byproducts of mechanized tunneling is that the number of skilled high-quality miners is shrinking. We are committed to a course of improving the mechanization for greater speed, higher efficiency, longer life, and hopefully a lower cost per cubic yard of excavation.

DEFINITION OF THE STATE OF THE ART

For the purposes of defining the state of the art, I have decided to consider two categories: first, systems that are most likely to be selected by a company approaching a job today, the best of the conventional methods and limitations of these systems. Examples of these systems are:

1. Rail Haulage
2. Rubber Tired Haulage
3. Vertical Haulage, Hoist and Crane
4. Conveyor Haulage

Second, I will discuss systems that, while less common or more specialized, have been used and may be expected to be used again, the developing systems. This second group is past the research stage but not so well developed as to be considered a standard or universal method. This is one of the areas to which a contractor looks to watch for improvements that will lower the overall cost of tunnel construction.

CONVENTIONAL SYSTEMS

When examining the first group, the "tried and true" methods, we find that it tends to seem redundant for tunnel people to debate the finer

points with other tunnel people. In fact, a person who purchased materials-handling equipment for a tunnel job twenty years ago could lock at an equipment list for a job to be bid next month and find only small differences in the set-ups for haulage, hoisting, and the like. Greater use of hydraulics would be the most noticeable change.

When selecting whether to haul on rail, track, or rubber, several factors must be considered:

a. diameter driven

b. length of haul

c. grade

d. method of excavation

e. the timing of the excavation cycle

The longer the haul distance or the smaller the bore, the more likely that muck removal will pace the operation cycle time. In a rock tunnel, large bore, conventional excavation, especially vehicular tunnels, a rubber-tired system is more often selected. When using a TBM, if the grade is not prohibitive (approximately 4% maximum), rail haulage is the most likely choice due to the round bottom and adaptability to conveyor loading sequence. In steeper grades or sloppy conditions, especially for shorter drives, a loader on tracks may well prove the most sure footed, despite the low speed. In each of these cases, whenever one is operating diesel equipment underground, the ventilation requirements are multiplied by the aggregate amount of horsepower involved.

Rail Haulage, Horizontal

If the contractor has selected a rail system or a rail and conveyor system, he is probably looking at one of six types of heading equipment: A Conway mucker, and Eimco mucker, a Hagglunds loader, a roadheader, a TBM, or a type of soft ground excavator shield. On a drive of reasonable length, these systems could be accompanied by a sliding floor. This is to allow flexibility

at the heading, either to keep an empty muck train available, to move the mucker out and a jumbo in, or the like. Other systems such as cherry pickers, "grasshoppers" or "tanks" have been used to jockey cars, providing an alternative for a switch or double track at the heading. However, except in situations with particular space restrictions, the simpler, more direct sliding-floor method is the preferred answer. In all but the shortest haul, the tunnel will become tube-locked if the haulage units cannot pass. In smaller bore, soft ground tunnels, the trains are often custom fit to pass or to go through air locks. The smoothest loading operation, when space allows, is to provide a double track beneath a gantry conveyor utilizing a tripper or flop gates so that one train can be loaded while the other track is used for moving in the next set of cars. The next best alternative, if there is not room for the overhead conveyor or double track, is the Hagglunds shuttle train, utilizing cars that not only transport muck, but can convey from the front car to the rear and transfer, loading the entire train. These, too, should be able to pass each other on a haul of substantial length. The advantages are being able to cut down on backup equipment and that the cars can unload themselves. If problems arise with one of the cars or its conveyor, it can be isolated, and the operation can continue, unlike having downtime on a mainline gantry conveyor. A problem with the Hagglund system is in bringing materials to the heading. If the material car is to be in front of the train, it is still necessary to have a riser conveyor that will clear the material car. If the material car is at the rear, a monorail or some other method of tramming material such as ribs or lagging the rest of the way into the heading is required. In any case, except when the grade is excessive or the bore less than approximately 15 feet in diameter, an economical rail or rail and conveyor system may be assembled that will keep pace with the excavation. The important factor is that before purchasing equipment for any system,

a contractor must know how many dollars it is worth to increase his haulage capacity. Conversely, he must analyze what the cost in time is if he elects to use a lower capacity, less expensive system. Assuming he can still meet contractual deadlines, it may be cheaper to use a less innovative system, save the capital outlay, and accept the lower production. The length of the tunnel and the contractual deadlines are factors to be considered when deciding if it is economically advantageous to install a materials handling system that is designed to meet the maximum output of the excavation.

Rubber -- Horizontal

Large, flat-bottomed tunnels are more adaptable to rubber-tired vehicles. Horseshoe rapid transit tunnels and drift work are often serviced by load-haul-dump units, low profile, front-end loaders used for tramming. An advantage in a conventional rock tunnel is that they have the ability to move the muck away from the heading, allowing crews to set steel and prepare for the next round. The muck can then be rehandled to take it to the point of disposal. In a larger heading, or heading and bench operation, especially in portal jobs, conventional loaders filling trucks is an attractive muck disposal method. On of the biggest disadvantages of this class of systems is that far more diesel horsepower is required, with accompanying ventilation problems. Tunnel invert and haul ways must be constantly maintained, and even then there is a great deal of expense due to abuse suffered by tires. These systems add a measure of flexibility with low installation cost and higher portability from site to site. However, there are more equipment units to maintain and operate. If the tunnel is serviced by way of a shaft rather than a portal, there is more involved in rehandling the muck. In a portal job, the trucks can haul to stockpile or disposal, away from the central staging area for the tunneling operation. The disadvantages are more operating and maintenance personnel and costs, additional horsepower required to move the same amount of muck, with associated fuel costs and ventilation

problems. The limitations are length of tunnel, and in the case of LHD units, speed and additional handling requirements.

Vertical Shaft Haulage

When vertical haulage is required at a shaft, the depth and the rate of muck handling are the determining factors. For a relatively shallow shaft, arbitrarily selected at 125 feet or less, a crane hoisting system is standard. The deeper shafts require a hoist system for muck removal, such as the Koepe hoist, with skips or car handling cartridge. The hoist has a higher initial investment than a crane and requires a sizeable amount of time and money to install and remove. It has the advantage of speed in dumping and, after the bugs are out, a relatively trouble-free operation. The hoist skips are usually charged by way of holding bin or measuring pocket, requiring sizeable overexcavation beneath the invert of the shaft. The bin is filled either by a rotary car dump or self-dumping cars such as a granby car if rail haulage is used, or by the LHD unit or truck if rubber tire haulage is used. The bin can be large enough to make the vertical hoisting of muck semi-independent of the horizontal haulage if there is enough muck to make this aspect financially attractive. If the job does not involve enough muck to warrant a skip charging system, the hoist can be fitted for car handling cartridges that will lift a muck box off of the chassis, carry the entire box to the dump scrolls at the top, and return the box to the tunnel level. Each of these pieces removes the muck at a different rate, but additional investment in a faster system with more sophisticated components has to be balanced against the cost of delay that would be incurred if utilizing a simpler but slower version. In a shallower shaft, a crane's slower cycle time is less of a problem. Most of the slower cycle time derives from hooking and unhooking cars and replacing the cars on the bogies or on the rail. However, the initial investment is lower. Portability is a large factor,

especially in jobs that are done in segments, or in which the mucking spread can be advanced to successive shafts. The resale market for cranes is larger, increasing the salvage value. If the unit has a major breakdown, it can be replaced more readily. It can provide additional service in the yard area, a function not possible with a hoist. However, it normally requires more labor in union-operated projects (oiler), a more experienced operator, and more maintenance than a hoist.

Conveyor Haulage

In a larger job, an alternative to either a hoist or a crane muck-removal system is the inclined conveyor. It is a time-consuming and expensive installation, requiring driving a slope, supporting the ground, installation of the conveyor, and backfill after removal. However, if space is available and there is enough muck to warrant the investment, it provides the dependability of a conveyor providing continuous haulage with the advantage of having the main service shaft free for transport of men and materials. An example of this system is on the Kenny-Paschen-S & M Howard Street project in Chicago.

Muck removal using conveyor alone from the heading to the shaft or portal is, generally speaking, not practical. Although the mines use conveyor haulage to great advantage, tunnels are not so adaptable. The mine can spread out in several directions and utilize a mainline belt fed by several headings. The tunnel is linear, and all its progress is in moving directly away from the belt. However, as Bob Mayo has said, there is a great difference between a 10,000 foot tunnel and ten 1,000 foot tunnels. We considered conveyor haulage when we bid the Cameron Run tunnels in Alexandria, Virginia, where the project called for eight tunnels, each only 200 feet long. However, unlike the other haulage systems I have mentioned, you have to devise a separate method of bringing ribs, lagging, tools, and repair parts into the heading.

SYSTEMS IN FIELD DEVELOPMENT STAGES

There are a number of other systems which have been tried, but with varying degrees of success. This second group of systems can be said to be in the field development stage.

Slurry and Pneumatic Pipeline

One of the more promising of these is pipeline transport, either pneumatic or slurry. Shields with bentonite slurry pumped into a sealed bulkhead behind a cutting wheel have been demonstrated as feasible. In England, the Nuttall-Priestley machine excavated over 4400 feet of tunnel, including difficult ground with rock in the invert and boulders in the sand layers. The system, offered in this country by Elgood-Mayo, moves the muck to the surface in the bentonite suspension after screening out the larger pieces of rock. The system is most adaptable to sands and fine gravels, or sandstone that breaks down into fine components. In a rock tunnel, even with a TBM, the process requires that the muck be passed through a crusher. When using the slurry process, large settling tanks must be provided and a supply line installed to continue the flow of the medium to the heading. Even when designed for as much as 20% solids, pipeline transport has a hard time with large angular or irregular pieces. The wear on the pipeline is a large factor, especially at the elbows and fittings. Adding additional line is no easy task because the line should be empty first. The muck is in suspension, not in solution, and will settle out in the line if not continually moving. The bentonite slurry system helps with this aspect. In addition, the volume of the medium required is far greater than the amount of muck to be transported. Therefore, in order to remove a yard of muck, about 12 yards of material must be handled by the system. The system requires booster pumps at intervals and, like the conveyor system, does not help a bit as far as moving

in tunnel supports, men, equipment, or more pipeline. The contractor has to be certain that he can expect the muck to be, or made to be somewhat homogeneous. A plug in the line or a pump breakdown can shut down the entire operation. Hydraulic pumping requires large settlement basins or separations at the surface followed by rehandling with a dragline or clam. Penumatic methods are more prone to plugging the line; air power can be an expensive and inefficient method for transporting materials in volume for long distances. However, in the proper ground, the pipeline method can be an attractive alternative for material transport. The contractor must have a high degree of certainty of the existing subsurface conditions. He needs the room on the surface for the basins or centrifugal separators. In the case of a slurry-face shield, he is able to eliminate any requirement for air locks (except for cutter wheel maintenance periods or pump breakdowns and emergencies) or tedious hand mining procedures and should expect that anticipated progress will be higher accompanied by less settlement on the surface. A change in the ground can leave a contractor looking at the heading with no way to remove the muck. While it is possible to use this system in soft ground with boulders, the problems associated with the boulders is substantial. Problems are being overcome, however, and the pipeline method may well become an inexpensive way to remove muck in many applications.

Monorail

Monorail systems have been tried on a small scale, attempting to provide a means of assuring a continuous supply of muck buckets to the heading and retain more working or travelling space below springline. Although we have all used small capacity monorails for moving materials such as ribs, lagging, or cutters from the material tramming unit to the face, these have been built-in units carried as a part of the back-up equipment, jumbo, or boring machine. A monorail system for muck removal would be a much heavier

duty system. It would have to be extended continuously at a rate to keep pace with the boring machine or excavator. The power unit would be substantial, expecially in a tunnel boring driven down-grade. The power unit would also have to provide for being able to stop the buckets independently long enough to be filled. These and other obstacles may well be overcome, but we do not visualize a situation in which such a system can promise advantages over systems currently in use.

Continuous Vertical Haulage

Exotic conveyor systems may prove economically advantageous in servicing vertical shaft haulage. Spiral or rotary conveyors may be developed that can be installed at a far lower cost than a headframe-skip combination. A ferris wheel type of bucket conveyor is at work on the DeSourdy project in Montreal. We expect that developments in continuous vertical haulage may contain the next advance in cost-saving methods for materials handling, but the track record that will persuade wide consideration does not yet exist.

Exotic Method

The people at Los Alamos are still working on the subterrene. If tunnel excavation by melting does develop to the point of being commercially practical, this technology will probably include modified variations on the materials handling methods already discussed. The smallest of holes will have little or no muck to remove, analagous to shoving a blind shield through Hudson River silts. The larger bores will displace the rock melted from the core, and the machine will include a cooler immediately behind the head of the unit. The result would be a material that could be handled in a standard format, even if special materials had to be used due to the temperature.

Summary

This is where we stand today, and I know that it seems as though there has been only small accomplishments in materials handling in twenty

years. However, tunnels are different from coal mines or ore mines. Our set up is linear and temporary. The job is only going to last for a short time. It is unusual to get a job where the actual tunnel drive is scheduled to last for three years or more. When equipment is bought for a specific project, there is often no guarantee that it will fit your next project. If the company intends to amortize the equipment over several jobs, the investment may still show on the books long after the capital outlay has been made, lowering any effective return on investment. Therefore, on longer jobs, each system has to be considered on its own merits for that specific project. If a piece of equipment represents a large innovation, it also represents a risk. The project that tries the new system will inevitably end up reflecting part of the system development costs in the project cost report. Assuming, for example, a contract to excavate a tunnel that should take 12 months to drive. And suppose there exists a new system that should increase your muck handling speed by 20%, costing $150,000 for purchase, installation, and operating costs. Assuming that TBM availability is 85%, the system could increase your ability to advance the tunnel by no more than 17% or 2 months. It simply may not be worth taking a chance on a more complex, more sophisticated system with little or no track record at an additional cost of $150,000 to save two months of labor and overhead. This is one of the reasons that the state of the art today has not made twenty years of progress in two decades, or why it has been said that contractors do not readily accept change.

There are techniques that can help a contractor speed up his haulage with existing or presently owned systems. Greater care in laying rail can speed up the locomotive haulage. The switches and the stretches nearest to the portal are most crucial. Often, not enough care is taken with the rail installation because at the time it is installed, the shifter may see

it as "footage lost" on his shift and decides to let the next shift straighten it out. Such decisions can come back to haunt everyone on the job in the form of derailments and slower haulage. The Shea Company, for example, has been using precast invert segments to provide easily maintained and uniform haulage ways, yielding higher tramming speeds and fewer equipment repair delays.

Overview and Government/Industry Relationships

In each of the systems I have cited, I have pointed out that haulage systems can be sized to keep pace with the excavation. The real limiting factor is the amount of muck to be handled versus the size of the capital outlay to be prorated over that volume. Excavation speed is increasing with newer techniques and equipment advances. The rate of tunnel advance will have to increase substantially before the capacity of present handling systems technology will be strained. This is not to say that every haulage system will keep up with the excavation. Economically, this may not be worthwhile. An example is one of S & M Constructors' current projects, Back River Tunnel in Charleston, South Carolina. This project involves over two miles of 9.5 foot bore through marl, a soft, self-supporting rock. The boring machine is capable of advancing 40 feet an hour or more. Theoretically, it is possible to run enough trains and install enough switches to remove the material at that rate. However, the cost of doing so, and the time involved in equipment lead time and switch installation is prohibitive. The end result is a project that meets the optimum economics by removing the muck at about 25 feet an hour. Therefore, the changes we look for in the next 10 years will primarily revolve around refinements to present systems with an economical balance and their effect on the environment.

I have stressed the fact that an advance in equipment ability has to be financially attractive in perspective to the particular job at hand. It boils down to the fact that, since our projects are short term in comparison to the mining industry, we have to realize the return on investment in a much

shorter period of time. Since so many of our projects are obtained under rigorous competitive bidding, we are pressed into choosing a method that will be most advantageous for the short term of that particular job. Working with a fixed-cost project, a contractor must be certain that the system chosen will perform at or lower than the cost in his estimate. A losing gamble in this area can cast a pallor on the remainder of the project, the game of "catch-up" ball. If a more coordinated approach could be taken to design of tunnel sections, there could be a small number of standard excavation diameters. This would be especially valuable on shorter tunnels. If a contractor is reasonably certain that a piece of equipment would be readily adaptable to a series of projects, he could justify amortizing the cost of the equipment over a larger number of jobs. This would effectively reduce the cost to the project for the purchase of new equipment, and increase the justification for a more costly, high efficiency system.

The specialized application types of jobs are the areas in which advances and innovations in equipment technology can affect the cost picture. Small bore soft ground tunnels require special logistics in muck hauling and traffic patterning. Jobsites that do not have operating area at the surface or insufficient room for a shaft of reasonable size can seriously limit production. Examples of problems such as these dealing with restricted working areas and minimum operating space are abundant in tunnel construction. Furthermore, work in urban areas poses additional restraints. A prime example is the subway work in New York's Central Park, adjacent to fashionable living quarters. Contractors have built sound reducing enclosures around the headframes to isolate the noise of the equipment and the muck handling. The Schiavone Company is setting up a hoist that will allow the trucks to be loaded at the bottom of the shaft, raised to the surface, and haul the muck away with no more disturbance to the neighborhood than any other ordinary truck traffic. In this system, as part of the project specifications, the contracting agency

opted to spend additional money on materials handling to reduce construction impact on the surrounding area. This type of extreme measure is indigenous to New York City, but it does serve to illustrate a situation in which restrictions outweigh simple economics in the planning for a materials handling system. It is in coping with severe or unusual conditions that the value of significant changes and associated development costs make the contractor more receptive to new ideas.

We are living in a time that places a premium on energy. Certain types of energy sources such as gasoline are precluded from use in underground construction. We all remember the quota, or rationing, of diesel fuel in 1972 and 1973. So energy considerations play a part in the decision-making process of choosing the equipment for a job. Any innovation that promises savings in energy will be an important step.

When diesel horsepower is used, ventilation problems increase as a multiple of the total horsepower required. Improvements in emmissions control, both in the engines and in the scrubbers, can yield savings in ventilation costs. Battery powered equipment is slower and expensive. Other electric units require trailing cables or trolleys. The optimum, of course, is a unit with the power and flexibility of diesel with the ventilation requirements of electric. A welcome development would be a unit that retains a good mixture of these qualities at a commercially practical price. This is one of the problems that can be dealt with when it is possible to use the slurry or pipeline system of muck conveyance. The tonnage to be moved by the locomotive is reduced to a fraction of the amount moved when the standard haulage is used. We still get back to the realm of specialized application.

Long range developments require initial research funds, field trials, and, finally, proving under actual construction site conditions. Since the majority of tunneling is built with public funds, a cost saving

idea will ultimately benefit the public. Since the public interest is served by lessening the environmental impact of construction, the demand for tunneling will continue. Therefore, it is reasonable to seek a method by which savings in construction costs can be made available to the industry at large and, in turn, passed on to the public who are footing the bill. I have kept returning to the problems associated with untried schemes being developed on fixed-cost, fixed-time projects. However, if innovations are to be introduced, the research and development costs have to be paid. So many of our present methods are adaptations of methods that have proved successful in roadway or building construction. Overcoming problems specific to underground construction and solutions to the shortcomings of systems now in use will certainly have to stem from measures instituted by those familiar with the problems. We have already seen methods by which the government can subsidize the development of a potential cost-saving method. The Department of Transportation, through UMTA, has agreed to pay part of the cost of installing precast liners in lieu of ribs and boards on a soft ground subway tunnel. By dealing with the contracting agency rather than the contractor, the agency was able to get competitive bids and, in effect, be subsidized for field development of a construction technique still in its infancy in this country. If a revolutionary system is to be tried, it embodies a long learning curve that extends beyond the first usage. Research and development money should be made available to help smooth out the cost of this introduction. When a contractor is working for an agency, be it an underground metro transportation agency, a state highway department, a sanitary commission, or any other public owner, the concept of a direct relationship between the contractor and DOT suggests potential problems. It would involve commitments to two different agencies with different goals. Attempting to fulfill the requirements of two separate "owners"

can sap the strength of the contractor's managerial and office staff. It would be preferable to establish a relationship, the format of which would be spelled out in the pre-bid contract documents and the administration handled through the contracting agency. In this way, there should be no unresolved questions as to contract completion priorities if the project were delayed by the new system changes. It would be used as a form of insurance against one contractor or one joint venture suffering unduly in the development of an advance that would benefit the public on subsequent projects. It could be in the format of a value engineering clause but with an objective and performance method that would be specified in the bid documents. A formula could be included for making that particular aspect of the project in the form of a target bid with the authority and the contractor sharing a portion of the post-performance savings or cost-overruns. The point is that if progress is to be accelerated, the incentive must be there, and there must be a form of guarantee that the contractor involved is not risking his future and his livelihood on an experiment. The contractor is willing to make certain guarantees when he has the freedom to choose his methods and when he has an accurate picture of the subsurface conditions. However, if there is to be a rapid departure from the "tried and true" methods, he must be assured that there is a reliable form of recovering a return on investment.

The research required for advancement of handling system technology would be best conducted by those directly involved in the manufacture of the components. They have the mechanical engineers who cope with the day to day problems of building better equipment for underground construction. The specialized nature of so many of the improvements we have seen is such that they start out to solve a problem in a particular application, and after trying it out, complete the development for a more universal application. The degree of specialization and the cost of gaining the experience is such that

the entry requirements to this type of work are generally quite high. It is far more reasonable to look to the established manufacturers for the real innovations.

The British have established a government agency whose function is to help to finance the development costs of technological advances in that country. The National Research Development Corporation will review the inventions and new concepts submitted to them. When they have determined that an advance contains sufficient potential, the NRDC is able to loan money to the inventor or to the company to complete the development and to market the innovation. When the system is used, revenues are generated under licensing agreements to repay the loan. The NRDC is even able to commit money towards performance guarantees, setting up guidelines where they will share a portion of a potential loss arising from the use of the new technique or system. If the system turns out to be a failure, the development funds are written off. If the system does indeed find a market, the advance money is subsequently repaid. It is their method of promoting British technology and providing a form of insurance and financing to aid in the rate of their technological advancement. This is an example of a method by which R & D funds can effectively be channeled toward acceleration of change in an industry.

The Department has also implemented field research and development by allocating funds for using new tunneling methods in a project that has no ultimate purpose other than to serve as a proving ground. The advantages are that the research team can control the experiment. If the project is delayed or if the method is, in hindsight, less than ideal, the operation will not be a stumbling block on a critical path for a water system or subway system that has to be completed. The disadvantage is that it is expensive research, and, therefore, must be reserved for the most promising of major innovations. One example of this approach is the Department's research on

placing continuous, cast-in-place, concrete lining behind a tunnel boring machine.

Cost/Benefit Ratio

To assess the potential of development and the net benefit of research costs, let me return to the excavation projection from "Tunneling: The State of the Art:. In the relatively near future, they anticipate in excess of 7.5 million cubic yards of tunnel excavation, and this does not include excavation for powerhouses or underground storage chambers. If a conceptual estimate is run on a system, there should be an estimate of the potential savings per cubic yard. Suppose a system showed the possibility of saving $1.00 per cubic yard of muck hauled, and it could be applied to one-quarter of the tunnels planned. The potential exists for a medium term savings to the public of $2 million. This must be coupled with the fact that, if successful, it would certainly yield a great deal more in the long run, beyond this over-simplified eight-year example. So the value is there, but it will take a willingness to invest dollars for a long term, with the return on investment to be reaped not by one company or group of companies, but by the contracting agencies and the consumers.

The level of research presently being conducted on material handling systems is hard to quantify. The large part of it is the work being done by suppliers of systems in a continuing effort to improve their products. However, unlike the work being done to investigate new lining techniques or improved excavation concepts, I do not know of federally funded research being conducted specifically on materials handling.

Potential Areas for Research

There are four areas that I feel warrant specific study by research teams. Perhaps the workshops will serve to probe into these in greater detail, and augment the discussion as to their potential.

First, the pipeline process of muck haulage could be further developed, to produce a reliable method for use behind high speed rock tunnel boring machines. The system would have to include the means of handling the rock from immediately

behind the machine, crushing the oversize pieces and pumping it to the surface. On a project the size of Chicago's mainline deep tunnel and reservoir plan, it would have to be able to handle as much as 350 solid yards of rock per hour, pumping it for distances of up to four miles underground and 250 feet vertically. Answers would be required for how to reclaim this type of volume at the surface, how to avoid delays during the extension of the pipeline, and many other considerations. If the long range target for this system is set on a large scale operation such as this, it may well prove to be a major cost saving concept in the long run. Second, the concept of continuous vertical haulage, whether by a spiral conveyor or another method should be considered. If a method could be devised for use in shaft sinking as well as removal of tunnel muck, the range of potential uses would be extremely broad.

Third, the use of precast tunnel inverts for use in speeding up tunnel rail haulage. Invert segments could have rail cast into it, thereby holding gauge and eliminating a great deal of the track maintenance and derailment delays that are now part of the cost of driving tunnels. The inverts could be an integrated part of the final structural design of the tunnel lining, and the rail simply left in place, providing easier access for future inspection or maintenance.

Fourth, high-speed, high power haul units that require lower ventilation for emissions. The speed and flexibility allowed by diesel is especially important on long hauls and with large volumes. Battery powered locomotives are slower, and require recharging after each shift. Trolley lines for power are not acceptable for many applications and trailing power cables are not practical. We need a unit that retains the power of diesel and that approaches the ventilation requirements and underground permissibility of electric.

Conclusion

At this time, present technology can produce materials handling systems that keep pace with excavation. Research and development are continuing that may well produce rates of advance in excess of 20 feet per hour in large rock tunnel boring machines. The need for advances in handling systems is inextricably linked to the technology advances in excavation and support. Improvement must be made in pre-construction geologic information and subsurface inspection methods. Unexpected subsurface conditions is one of the main sources of cost overruns and delays in the industry.

I expect that refinements to present use systems will evolve from the efforts of those who manufacture them. But if the materials handling systems are to keep pace with the next generation of boring machines and excavators, there will have to ba a planned, systematic, centralized approach toward finding solutions in the four areas outlined.

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PAPER 5

Rubber-Tire Vehicles

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A major advance in rubber tired haulage occurred with the introduction of the load haul dump family of equipment in the late 60's. This Load Haul Dump (LHD) equipment has in most cases superseded the use of a separate mucker and haul trucks when the tunnel size requires inline loading from the heading with rubber tired equipment.

Prior to this specialized equipment the LHD concept was used in tunnel construction using standard cyclic loading machines. While adequate for short distances their basic design was not recommended for haulage with loads for long distances.

The selection of rubber tired mucking and haulage equipment for various tunnel sizes has been studied in detail by everybody involved with preparation of bids and project planning. The simplest answer to the question is to put in the equipment that allows the shortest possible muck out time in the heading. In the case of a short 2,000 foot tunnel, using this criteria, you will purchase too much equipment and in the case of long tunnels you might be purchasing the wrong type of equipment.

The selection of rubber tired equipment for haulage is dependent on several major variables. Amoung these are:

1. Size and geometry of the excavation.
2. Total single heading length involved.
3. Tunnel grade.
4. Secondary considerations.
5. Engineering design.

I will go through these variables and to simplify the discussion, I will treat them individually. Arriving at a final selection, must involve some trade offs when all the variables are considered.

A contractor will be greatly influenced by the equipment he presently owns when evaluating a new project. A mining company can usually look at a longer equipment utilization and can be more independent in the selection for a new project.

1. SIZE AND GEOMETRY

Some general criteria for selection of equiment based on tunnel size should be:

If you can put a cyclic mucker in a heading to load large trucks, do it. If the heading layout dimension drawings are tight for the cyclic operation of the mucker during loading, by tight I mean it fits well on paper, you may be asking for a problem. A method of overcoming this, if the head room is available, is to use special side dump buckets and parallel the truck when dumping. The tunnel geometry and possible location of a top heading may recommend this. You might consider smaller trucks and a smaller cyclic mucker. At this point, you would be comprising production to stay with the method.

There are numerous combinations and possibilities available with this method but before locking into this system of excavation, a simple cost comparison should be made against straight LHD equipment.

From a contractor's standpoint, because of union requirements and limited secondary activities, with a single heading tunnel, the cost difference might justify LHD equipment even if increased mucking out time is required.

If a tunnel is sufficiently wide, consideration should be given to allowing LHD units to stockpile material behind the heading. When this stockpile is finished the jumbos could return to the face. and the LHD equipment continue the mucking by rehandling to the waste area during the following heading operations.

Generally speaking larger tunnel sections are associated with short drives, such as diversion tunnels, highway tunnels and rapid transit stations where this type of rehandling can apply.

Numerous projects allow for multiple heading operations where the cost of the work is not totally keyed to a single heading production. This type of project requires flexibility because you will want to take advantage of opportunities to vary your basic plan when you do the project. An example of this would be to use two rubber tired jumbos that can be used side by side to get face coverage. When they are moved, it will be much easier and less time consuming. I have seen projects based on a swing heading operation that require almost as much time to move the jumbo as it does to drill out the next round. In the case of haulage equipment, this is also true. Until recently most large haulage units in the 35 ton range have been off highway trucks adapted for tunnel use or special rock body trucks with standard tractors. LHD units, while basically for tramming, are well suited for cyclic loading of trucks. This gets back to the basic premise that what ever gets the muck out the fastest should be used. LHD equipment cannot load standard off highway equipment and this maximum mucking capability is lost without special low profile trucks. These high tonnage underground trucks are a natural growth of using the cyclic mucking potential of

LHD units. The ability of the LHD to self load for efficient tramming has produced good mucking machines. Again mining companies have made this change easier than contractors because of their longer project durations.

Up to this time the duscussion has been on tunnels large enough to allow consideration of loading trucks in a heading by side dumping methods. Prior to elimination of truck loading in a heading and going to inline loading and haulage, consideration should be given to end loading telescopic type trucks. In this case, ejection type buckets are required. You need a total width of the truck and mucker plus a minimum of five feet. This approach has merit for low head room tunnels in the 21 foot wide range. The final size of a tunnel in most cases is fixed in the specifications for civil construction contracts while mining companies have more flexibility to allow the tunnel size to be adjusted to accommodate a more economical excavation method. From a footage per day standpoint, using rubber tired equipment, this would be an ideal arrangement for this width of tunnel in my opinion. This width of 21 feet can be reduced by using narrower haulage and mucking equipment and believing clearances can be a little tighter. You approach the same conditions of economics of return as when considering smaller equipment to allow side dump loading in the large tunnel section previously considered.

Below the 20 foot width range inline loading and haulage is required. This basic system is used either with rail or rubber tired equipment and is inherent due to the tunnel's limited width.

The history of rubber haulage for this size of tunnel shows that overshot track equipment dominated tunnel excavation in this size range prior to LHD equipment, when tunnel lengths dictated rubber tired equipment.

The gravity beds of the trucks previously used with overshot equipment, required a higher degree of operator coordination than is required with more modern trucks. This is best explained by an example of a job I was on in Colorado. To make the dump, it was necessary to approach the dump point with a hand on the bed release lever. At the proper time, after a slight acceleration, the dump lever was pulled, brakes were applied and maximum braking was used to tilt the bed. Reaction to get maximum braking was taken from the steering wheel. The purpose of this sequence was to insure loosening the cleaning plate on the bottom of the bed. I remember everyone's concern when dumping over a steep bank into the canyon, and a stout summer hire walked into the job trailer with the truck's steering wheel in his hand. This equipment today has hydraulic cylinders for dumping. The innovations in equipment that have come about in tunnel excavation are largely the result of superior hydraulic systems and this power system will no doubt be a key factor in the improvements to come.

When considering inline loading and haulage for smaller tunnels, less than 20 feet in width, the bigger the better has merit. But the pricing structure of LHD units over 10 cubic yards does not justify this selection except for unique conditions, such as projects requiring several units. From a contractor's standpoint, if he can get two for the price of one with the same total yardage

capability, he has automatically acquired a working spare. It is an uncomfortable feeling in a management position to realize a single unit's downtime can shut down a job.

In the upper limits of this tunnel size, say 17 to 18 feet, the ability to pass easily with 8 foot wide machines is assured. When widths do not allow this, passing nitches can be provided to allow this two way traffic. If the tunnel is to be unlined, this is easily done without much concern for the extra cost.

The most important consideration with LHD equipment in small tunnels is the minimum tramming width for good haulage speeds and clearances for the ventilation line. When laying out this tunnel section to appraise these restrictive conditions, an early committment to how much money you will be willing to spend in the raodway for items such as surfacing material and overbreak concrete in the lining section, needs to be made. At least 9 inches of loose material is required to maintain a good haul road. Haul speeds of 12 miles per hour with a total clearance of 6 feet is reasonable. Any high bottom left behind the heading from improper blasting will be a source of constant problems. It is difficult to keep enough surfacing material in these areas because of the heavy tire loading from the equipment. Again, you can reduce the haulage unit width at a sacrifice of load carrying capacity to handle this restriction. In some cases this is a necessity, if you want to stay with LHD units for narrow tunnels rather than go to rail.

The above discussion covers the selection process for tunnel based on size and geometry.

2. TUNNEL LENGTH CONSIDERATION

A question exists when selecting the proper type of excavation methods for required inline loading tunnel sizes such as a 14 foot horeshoe shape.

I have made cost comparison studies based on job experience, and from a contractor's view point, LHDs will be cheaper for tunnels in the 7,000 LF range. This can be extended to 10,000 LF with the introduction of a truck at a rehandling station. This is based on a length comparison without major secondary considerations.

These maximum distances are based on many factors, but the limiting cost factor is usually the extra capital cost of rubber tired equipment versus a few more muck cars with rail.

As rubber tired equipment is taken greater distances, the ventilation requirements for the increased horsepower can become unrealistic.

When selecting the haulage method for questionable lengths of single heading tunnels, alternative cost estimates should be made to determine the method.

To achieve the above distances, it is necessary to provide rehandling drifts at approximately 1,000 foot stations throughout the tunnel length. These must be 40 feet in depth. This method was used to drive a 4300 LF tunnel on a 3% adverse grade for the Sacramento Municipal Utility District by Dravo Corporation in 1970. The initial haulage equipment on the job consisted of one ST8. When it became apparent after using the first rehandling drift that higher productions were possible, a second unit, an ST-5B was added.

The effect of these drifts was to reduce the heading operations to a series of 1,000 foot tunnels. The overall average footage was 42 feet/day and this included 25% steel supports at random locations. The rehandling drifts were selected to be in rock section tunnel.

The LHD equipment was also used for all secondary activities such as hanging fan line and hauling in steel supports.

Productions varied but were maximum when new side drifts were opened. When the jumbo moved back into the heading, the LHD units rehandled out to the portal.

The limitations were very evident at the third rehandling drift that this was the practical limit for 13 cubic yards of LHD capacity without delaying the drilling crews potential advance. It was a question at times of hanging fanline or mucking out the drift to make room for another round.

To improve the rehandling operations, these drifts were lined on the invert with concrete to both reduce tire wear and allow second gear loading for the rehandling operation.

The required tunnel concrete lining which included the full invert and arch concrete in steel supported sections was transported, and in the case of the invert, placed with the LHD units.

I believe the general acceptance of LHD equipment in underground construction stems from its versatility to do the total job as well as its mucking capability.

In larger tunnels, say 30 feet in diameter, that allow the direct heading loading of trucks, the muck out rate will be better than with rail. The problem is the cost of supplying enough trucks to keep the loader operating at maximum efficiency. With rail haulage, sufficient muck cars are taken in to insure the full muck out of the round.

The ventilation requirements while increased are more easily met because of the larger cross section and the ventilation line can be kept out of the travel way even if it needs two lines to satisfy the requirements.

Rehandling as in the case of narrower 14 foot tunnels can extend the effective distance up to 15,000 LF for tunnels of this size.

In conclusion, the practical single heading distance of rubber haulage with a rehandling scheme is the ability to remove the previous round during the time of the drilling and blasting operations of the next round. To determine the number of truck haul units to arrive at this limiting distance, the cost of the rubber tired plant and equipment must equal that of a rail set up with adjustments for labor differences and equipment operating costs. Cost penalities for these rehandling stations must also be considered.

3. TUNNEL GRADE

Any grades that exceed approximately 3% adverse to the haulage, favor the use of rubber tired equipment. A theoretical distance that can be done at the same cost with either rail or rubber should be done with rubber because of the safety considerations involved.

Rubber tired equipment can operate on 27% grades without cable assistance provided the road surface is concrete. This adaptability to steep grades has eliminated the need for shaft construction on some mining properties and allows an ore body to be exploited along a longitudinal axis. With cable assistance, the LHD equipment can increase this maximum grade.

To date very little civil design work has considered this unique advantage of LHD equipment in the layout of projects.

4. SECONDARY CONSIDERATIONS

When the economical distance for rubber tired equipment is determined, you should consider paving the invert to increase this distance.

If the job specifications require invert concrete it should be used as a construction tool during the excavation operations. This invert lining is normal in many hydroelectric tunnels in the west.

Since any concrete work is a line item in the schedule, it will not effect the total job schedule to place it early, except for the cure time that should not exceed 72 hours from the end of the last pouring operation.

If concrete paving will allow a 30% increase in haul speeds, you should expect at least a 20% increase in the economical distance when compared to rail operation.

The equipment operation cost will be reduced, especially that of abrasive wear and case breakage of tires.

While I have mentioned well maintained haul roads, it is difficult in a water environment to keep the fines from working out of the roadway material and developing into a loose roadbed.

Two problems with this paving that must be controlled, are excessive speeds and rock spillage. The operators seem to try to make up for the lost time when they were hauling on the old roadbeds and the fact that the high bottom locations they had to slow down for are now gone.

It is obvious that rocks on an unyielding concrete surface from spillage are of more concern than in a loose roadway. The break point between the new concrete paving and the continuation of the natural rock roadway to the heading, should have an effective bump in it to trim the bucket before the machine progresses on the paving.

An additional method of extending the length of rubber haulage, would be to install a conveyor system. This is impractical because of cost for a contractor, but has probably been done by mining companies who will continue to use it as part of the future operations. Without a crusher ahead of the belt this application seem futile. While some rock has unique breakage properties, it is difficult to depend on consistency. Adding additional holes to the round to maintain the consistency, beyond that necessary to pull the rock, is not the answer.

Since large LHD units can handle muck two to three times the size required of the best rail mucking equipment, this capability should be used to minimize the number of holes and speed up production.

5. ENGINEERING DESIGN

The only practical method of excavation in areas involving multiple grades and size changes, is with rubber tired equipment.

As previously discussed, rubber tired equipment means flexibility in a job.

In the case of rapid transit facilities, I believe that the performance levels of rubber tired equipemnt can be better utilized in the layout of the civil design. The ability to excavate steep

grades could be used to excavate inclines for escalators rather than relying on major open cut excavations immediately adjacent to stations. It might be possible to locate escalators away from the main streets to less conjested areas, where rock is closer to the surface. These escalator inclines could be used to haul out muck and return with supplies during construction of the stations without the need for expensive temporary shaft facilities.

Some of the high cost associated with transit systems is due to the nature of the rock or lack of it at the ideal transit level. By deepening some stations into better rock conditions with these inclines, many of the support problems can be reduced.

If transit system rolling stock can accept steeper grades to assure eliminating mixed face conditions, rubber tired haulage can accommodate these grades.

LHD equipment has been used to excavate steel segmented lined tunnels. This has required installation of timbered roadways. It seems possible that precast concrete invert segments that would provide an initial haulage road and the final transit track bed are reasonable to consider for future designs.

Before discussing the potential improvements in rubber haulage, I think the fact that the Conway rail muckers are basically unchanged in the last 40 years, should make us realize that some equipment is basically correct as it is. In my opinion, this will be true of LHD equipment.

Those areas of possible improvements with rubber haulage will come from the needs of mining companies considering the economies of new developments.

Among these might be:

1. Cleaner diesel engines and a near perfect treatment of exhaust contaminates. This will probably be done by others to the benefit of underground construction.
2. Tires - the bulk of the equipment operational cost for rubber haulage must become extended life items.
3. New primary power units, such as combination battery and trolley motors with regeneration for braking. This will complement the expanded utilization of electric service lines required with hydraulic drills.
4. Improvement in the ratio of payload to dead load in basic designs.
5. Buried electric cables for steering rubber tired equipment in tight quarters at maximum haul speeds.
6. Combination rubber and rail undercarriages to utilize the best of both systems.
7. Rubber tire inline loading machines to load trucks directly.

I am sure many of you can add to this list and basically this is the purpose of our meeting here today. Thank you.

PAPER 6

Rail Systems in Mining

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RAIL SYSTEMS IN MINING

The options of materials handling in the mining industry have expanded into several new areas. Rail systems have played the most important role.

Since the aspects of the industry are so varied, there were many distinctions that could be made. Mainly for purposes of analysis, the role of the rail system as it relates to underground mining will be divided into five areas:

1. Materials gathering machinery
2. Ore cars
3. Locomotive power
4. Rail and road beds
5. Maintenance

Materials Gathering:

At the present, the air or electric powered machinery do the lions share of the work. The metal and non-metal mines throughout this state that use rail, generally use the rail mounted overshot mucker. Bucket sizes range from less than ½ yard to 3 yards or more. Thier many years of use have produced a product that is highly reliable. Using a maintenance program in conjunction with the equipment reduced breakdown from 30% to less than 5% of working time, with air driven mucking equipment at Henderson. In the last decade, the tunneling industry has been making wide use of the so called, "Flying Carpet". In essence, it is a movable steel floor which advances with the face. It can be designed at a length long enough to carry the mucker and muck train for a complete muckpile, along with a parking point for the jumbo drill. It has several operating advantages in addition to high speed at-the-face switching.

Since it's leading edge is usually within 10 feet of the face, a good portion of the muck pile is deposited on the carpet, thereby facilitating the mucking portion. As the rear of the carpet advances, it leaves a smooth flat floor upon which to lay track. Experience at Henderson Tunnel showed muckout time for a 150 yard muckpile was 60 to 70 minutes, using a Conway 100-2B mucker with 1½ yard bucket and 10 cubic yard side dump Moran cars. Track laying could be carried on behind the carpet without stopping the mucking operation. In spite of the types of equipment available, the concept of the mucker to muck car transfer of ore has stayed relatively static. This is one area I believe more research is needed, to refine it or develop new ideas.

Ore Cars:

The choices of cars and unloading arrangements are wide enough to fit any operations' needs. Capacities can run from ½ ton to 125 tons or more. Unit train requirements usually call for loading and unloading in a continuous operation, so as to maximize train use. As an example; at Henderson, a 30 car train can be loaded at the rate of 50 tons per minute and unload ore from its 22 ton cars in 1½ to 2 minutes. The industry has a tendency to go bigger and bigger on capacity in an effort to haul more material at the lowest cost per ton mile.

An interesting article that appeared in "Railway Age",(1) experiencing the effect of 125 ton ore cars on 133 pound rail, shows excessive rail wear due to high wheel load on rails. It appears that a point of diminishing returns is being reached in this area.

Locomotives:

Locomotive power has developed into several important areas over the years. Excluding the steam engines of years past, these are grouped into five categories:

1. Diesel
2. Battery Electric
3. All Electric
4. Battery
5. Diesel Electric

Diesel

From my experience, the diesel locomotive provides a safe and reliable form of power in underground operations. Its' price is generally lower than an electric unit. The diesel is under close

(1) Reference article "BIGGER BUT NOT BETTER"

scrutiny in areas of emissions and fire control by the state and federal governments. There is a move in the federal government to make it mandatory to have automatic on-board fire suppression, and appears that this will come to pass in the near future. This will raise purchase and maintenance costs.

During development at the Henderson Tunnel, it was used in conjunction with battery-trolley locomotives. The diesel provided many functions including main line haulage during power problems.

Battery Electric Locomotives:

These units are a reliable and extremely useful locomotive for both fixed line and face haulage. Units of this type can run to 45 tons in weight. Their use was incorporated in driving 7½ miles of the Henderson Tunnel.

Using ASEA battery electric locomotives on 25 tons, these units could run along the main part of the tunnel by contacting a single trolley wire. The batteries were charged when the loci was running on trolley mode. At the face, the batteries provided power. Since battery voltage is only about 25% rated traction motor voltage, this is a slow speed arrangement. Battery-electric unit is used on fixed rail lines underground, where it is not desirable to have trolley wire in the train loading areas. This concept was initially considered for the Henderson Project but was dropped because a loci on each end of the unit trains would not lose contact with the wire through the loading operations.

All Electric Locomotives:

There seems to be a trend towards the all electric locomotive in fixed haulage lines in underground operations. The Kiruna Mine in north Sweden employs fully automated 65 ton locis as does the

Halemba and Lubin collieries in Poland.

In this country, the Bingham Pit near Salt Lake City uses both 90 ton and 128 ton all electric locomotives at adverse grades up to 4% against the load to haul 14 miles from pit to mill. Hrnderson uses 55 ton locis at adverse grades to 3%, with a distance of 15 miles between load and dump points.

Installation of the electrifaction to power this system is initially high. Costs ranging from $80,000 to $130,000 per track mile, or more. The investment will be offset by operational savings in loci maintenance, and replacement costs. In addition, the whole system is quiet and so is more agreeable to the working environment.

Rail and Road Beds:

This area has different requirements depending upon the permanence of the rail. Generally speaking, the construction phase calls for a lighter rail to handle equipment during development with tie spacing being figured from wheel load, equipment speed and other pertinent factors. It's relative stability is at the mercy of water, so adequate drainage by ditch, flume or drain line is a must.

The permanent installation of track must, of necessity, cope with conditions for periods of years. Aside from proper ballast material, the use of concrete for a base in tunnel floors has its advantages and disadvantages. Where double track systems exist in tunnels that require close proximity of passing trains, concrete has provided an answer. When this base or invert lays on compacted ground, an adequate and strong drainage system must be installed at the outset, to prevent destruction of the invert by water pressure.

Continuous permanent rail installation can be done at a rapid rate when it is organized properly. In one application, approximately 100,000 feet of track was brought underground and installed to specifications in 33,000 man-hours.

Use of continuous rail sections have helped to increase the speed of trains besides reducing the amount of harmonic action on rail structure. After rail installation, it is necessary to install rail anchors to prevent rail slippage. This is especially true in tunnels where grades are involved. Movements of over 4 feet in 5 miles of rail have been observed and measured in one case.

Battery Locomotives:

Still find much use in underground operations. Their advantages are reliable power in remote development areas and smaller operations. They can be run on a one or shift basis with no additional space for charging. However, additional area is needed for a recharging station, should three shift operation be the plan. Since batteries are the primary expense, it is well to consider that economy is up to 25% better on a chopper control unit, than for conventional resistor control(2).

Diesel Electrics:

Still provide most of surface haulage power, however, their application to underground operations is not readily utilized. These units are generally restricted because of mine opening size and ventilation problems since these units are usually quite large.

Maintenance:

This phase was installed because too often an operation gets bogged down in breakdown maintenance work, with subsequent stoppages of production. Effective planning and implementation of a preventive maintenance program is essential for long term productivity.

(2) Reference article "How to Design an Underground Rail Haulage System" by S. Scott, K. Hendstron, Canadian Mining Journal.

Along these lines, there is computer circuit analyzers that can be applied to locomotives. At present, this computer system is being examined for use by Henderson in an effort to upgrade fleet availability. Should a preventive maintenance program be implemented at a site, strict cooperation by the operating departments is mandatory for the program to work.

There is one area that bears consideration and that is automation. It can be applied to electrified systems since the technology has been with the industry for years. With spiraling labor costs, this should be an area of interest. To attain a reliable automatic system presumes a high fleet availability since on-the-road failures would significantly affect tonnage. Another benefit of automation results in the removal of human operating errors. As a comparison of manual versus automation; manual operation costs for power, labor and supplies is running about 15% of costs per ton at Henderson. It is anticipated that these costs will be cut by 50% when automation is in effect.

Rail systems as they relate to mining have been so diversified over the decades that these few minutes could never hope to touch all facets of it. I am sure that each of us concerned with rail systems could add much in each area. So with these thoughts in mind, I am looking forward to exchanging ideas and experiences with you. Thanks for your time.

PAPER 7

Conveyor Systems

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Introduction

Conventional conveying systems, particularly the belt conveyor that is set up to move material on a relatively straight path, are used quite routinely in underground and surface mining situations. The technology is well-developed and well-documented.

A part of the overall conveying system for mine applications that has not been well-developed or well-documented is the interface machinery that is required between a moving mining machine and a conventional conveyor when it is desired to provide continuous haulage of the mined material away from the miner.

The emphasis of this paper will be on the interface machinery rather than on the conventional part of the conveyor system.

For years the link between the mining machinery at the face and a conventional conveyor has been a common problem area for underground and surface mining operations. The lack of practical conveying devices to provide a continuous transfer of material away from the miner has probably discouraged the use of conveyors in many applications, and has encouraged the continued use of cyclic haulage devices such as rail cars, trucks, shuttle cars, and buggies.

It has been recognized that where a mining situation is suitable for their use, conveyors can provide significant economies for moving large amounts of material. If improved systems can be built to provide continuous transfer of material from the miner to a conventional belt conveyor, the benefits of conveyors can probably be extended to many more mining situations.

Background

The principal source of information for this paper is the work that was done by Joy Manufacturing Company on a project for the Bureau of Mines in 1974-1975. The project had the title Study of Continuous Face Haulage Systems, and it carried the Bureau contract number HO 242025. The final report was dated December, 1975.

The study related to continuous face haulage systems in underground coal mines. It was, specifically, a study of the link between the miner and the conveyor (or some other conventional system) that we have discussed in the introduction of this paper.

There were two main reasons for undertaking the continuous haulage study, the first being to find a safer system to move coal away from the face than the predominant shuttle car system, and the second being to try to advance the state-of-the-art of continuous face haulage as a means of increasing coal production.

The study analyzed the continuous face haulage problem and the various attempts that have been made to solve it. A determination was then made as to which continuous face haulage concepts have the best potential for being developed further into practical and effective systems. The emphasis was on planning to use available hardware and technology, rather than relying on long-range development of new hardware and technology.

The study also tried to uncover promising haulage ideas from other industries that could be applied to underground coal mining. Nothing new of this nature, however, was discovered during the program.

To put the subject into perspective before getting into the discussion, it should be emphasized that not many of the continuous face haulage concepts that have been tried have worked well enough to have survived. In spite of a lot of research and development over the past twenty five years by manufacturers and by mining companies, there are not more than a few hundred underground coal mine sections in the United States that have any form of continuous face haulage system in operation at the present time. The bulk of the face haulage is still handled with shuttle cars.

There have been encouraging advances in some of the hardware developments, however, in the past few years. The best example is probably the bridge carrier type of system that is the most common workable system being sold commercially at the present time. This type of system is manufactured by Jeffrey, Long-Airdox, and West Virginia Armature Company. Still somewhere between the development stage and full commercial production are two flexible conveyor systems being field tested by Joy Manufacturing Company. Known as the Serpentix conveyor and Flexible Conveyor Train, these developments show promise for the future.

A side benefit from so much intense investigation will be such hardware developments as improved bridge conveyors, improved belting, lightweight easily-installed monorail systems, and various minor hardware improvements that will benefit other mining machinery engineering projects.

Discussion

The following discussion will concentrate on continuous face haulage concepts that have either proved to be workable or show a considerable potential. Anyone interested in the historical aspect of other ideas that have been abandoned is referred to the report mentioned in the preceding background information.

Pneumatic conveying and hydraulic conveying were included in the Joy study but will not be covered in detail here, partly because they are to be the main subjects for other papers at this meeting. Our general conclusions regarding these concepts relative to their potential for underground coal mining might be of interest, however.

Concerning the two types of pneumatic conveying systems, the pressure system and the vacuum system, we concluded that the pressure system must be ruled out completely because of safety considerations, since a rupture in the system could leak large quantities of the coal-air-methane mixture into the mine atmosphere.

The vacuum system does not have such a disadvantage, since any rupture sucks air in rather than letting the conveyed material out. However, it turns out that a pipe about 34 inches in diameter is required to convey the material at the desired 10-12 tons per minute rate. The practical problems of designing equipment to be flexible enough to follow a continuous miner when this kind of duct size is required was just one of several factors influencing our judgment that pneumatic conveying did not appear to show much promise for continuous face haulage in underground coal mining.

Regarding hydraulic conveying, we concluded that this concept had a definite potential for use in underground coal mining, but as a device for continuous haulage at the face we believed it was limited by the design problems connected with handling the heavy, large-diameter flexible hoses that are needed to carry the slurry and the incoming

water, and by the design problems associated with the face machinery that is needed to crush the coal, mix the slurry, and pump the slurry into the flexible lines. When we wrote our final report on these various concepts, the design problems mentioned here had not yet been fully resolved.

The continuous face haulage concepts that appear to have the most potential at the present time are listed as follows:

1. Bridge conveyors

2. Bridge conveyor - bridge carrier combinations.

3. Monorail-mounted transfer conveyors.

4. Monorail-mounted bridge conveyors.

5. Monorail-mounted Serpentix conveyors.

6. Monorail-mounted Flexible Conveyor Trains.

In underground coal mining applications, most of the above devices are designed to handle material flow rates of from 5-6 tons per minute to 10-12 tons per minute, which is the range of output expected from continuous miners or loading machines.

It is also desirable to have a surge flow capacity designed into such equipment that will handle material flow rates as high as 15-25 tons per minute for periods up to 20 seconds, since this type of discharge sometimes comes from the miner.

Regarding the capacity to handle lumps, it is quite normal to have pieces of coal or rock in the miner discharge up to a size that is 12 inches cubed. This would indicate that a continuous haulage system should be able to handle this size of material as a matter of routine.

Occasionally larger pieces will come off the miner tail conveyor, and these could be as large as 12 to 18 inches thick and 3 to 4 feet on a side. When such unusually large pieces appear, either the continuous haulage system must have a built-in means for reducing them in size or

they must be handled on an exceptional basis by being broken up or moved aside by manpower.

All of the above capacity requirements must be handled without excessive spillage, not only in the interest of efficiency but also to comply with the mandatory safety standards, since loose coal must not be allowed to collect in any appreciable quantity in active workings. This consideration requires a lot of design attention at any transfer points in the system.

Before discussing each of the listed conveying concepts, there is one feature that they share that seems to be important in making them work - they are all positively guided along the path they are required to take to follow the mining machine. Many concepts that have failed have not had this feature. An example is a train of wheel-mounted cascading conveyors. These are sometimes called self-tracking trains. In practice on a rough mine floor they sooner or later don't go where they should, and part of the train winds up jammed against the rib. Operating people soon lose patience with this arrangement.

Positive guidance stands out as a feature of the successful systems, exemplified by the steerable bridge carriers under the control of an operator, for a floor-supported system, and by the monorail track used for various roof-supported systems.

Bridge Conveyors

Bridge conveyors have been in use in underground coal mines for about 25 years. Originally they were used to connect a miner or a loading machine to a room conveyor. In some applications they formed a connection between a miner or a loader and the tail piece of an extensible belt. Some installations of this type are still running where the mining practice is to run just one entry at a time, cutting the crosscuts halfway through on either side as the entry is advanced.

The bridge conveyor has more lately been used as an element in other continuous face haulage systems, providing a link in longer-reaching devices that must be used where the mining plan calls for three, five, or more entries to be advanced at the same time.

Bridge conveyors for underground coal mines are generally 30 to 40 feet long, a maximum of about 4 feet wide, and have simple steel frames designed for strength and rigidity with a minimum of weight. The conveyor generally runs the full length of the frame, and may be a flat belt, a troughed belt, or a chain type. The belt type of bridge conveyor is generally equipped with 36 inch wide special light-construction belting running about 400 to 450 fpm, giving a capacity of 8-10 tons per minute. The chain type bridge conveyors carry chain widths up through 28 inches, running at speeds up to 300 fpm, giving a capacity up to 8 tons per minute.

Drive horsepower on bridges run from 7½ to 20 horsepower. The belt type conveyors may have the belts supported on rollers or on stainless steel plates.

For underground coal mining applications, bridge conveyor overall length is restricted to about 40 feet by the narrow mine passages that must be negotiated. For tunnel applications or for surface mining applications where space constraints are not as severe,much longer bridge conveyors can be visualized.

Bridge Conveyor - Bridge Carrier Combinations

The usefulness of bridge conveyors has been increased in underground coal mining by combining them in series with a crawler-mounted vehicle called a bridge carrier.

Bridge conveyor - bridge carrier systems are the most prevalent continuous face haulage systems to be found in use in U.S. coal mines at the present time. Approximately 150 such systems are operating, split roughly equally between belt-type and chain-type conveyor designs.

A bridge carrier is essentially a bridge conveyor mounted on crawlers, which moves under the control of an operator. It forms a connecting link between two bridge conveyors. Figure 1 illustrates a bridge carrier with a chain-type conveyor. Figure 2 shows a bridge carrier and two bridges forming the link between the miner and a room conveyor. Sometimes two bridge carriers are used to link together three bridge conveyors. With 40 feet of length on the bridge conveyor and 30 feet of length on the carrier conveyor, a three-unit system provides approximately 130 feet of reach from the face to the panel

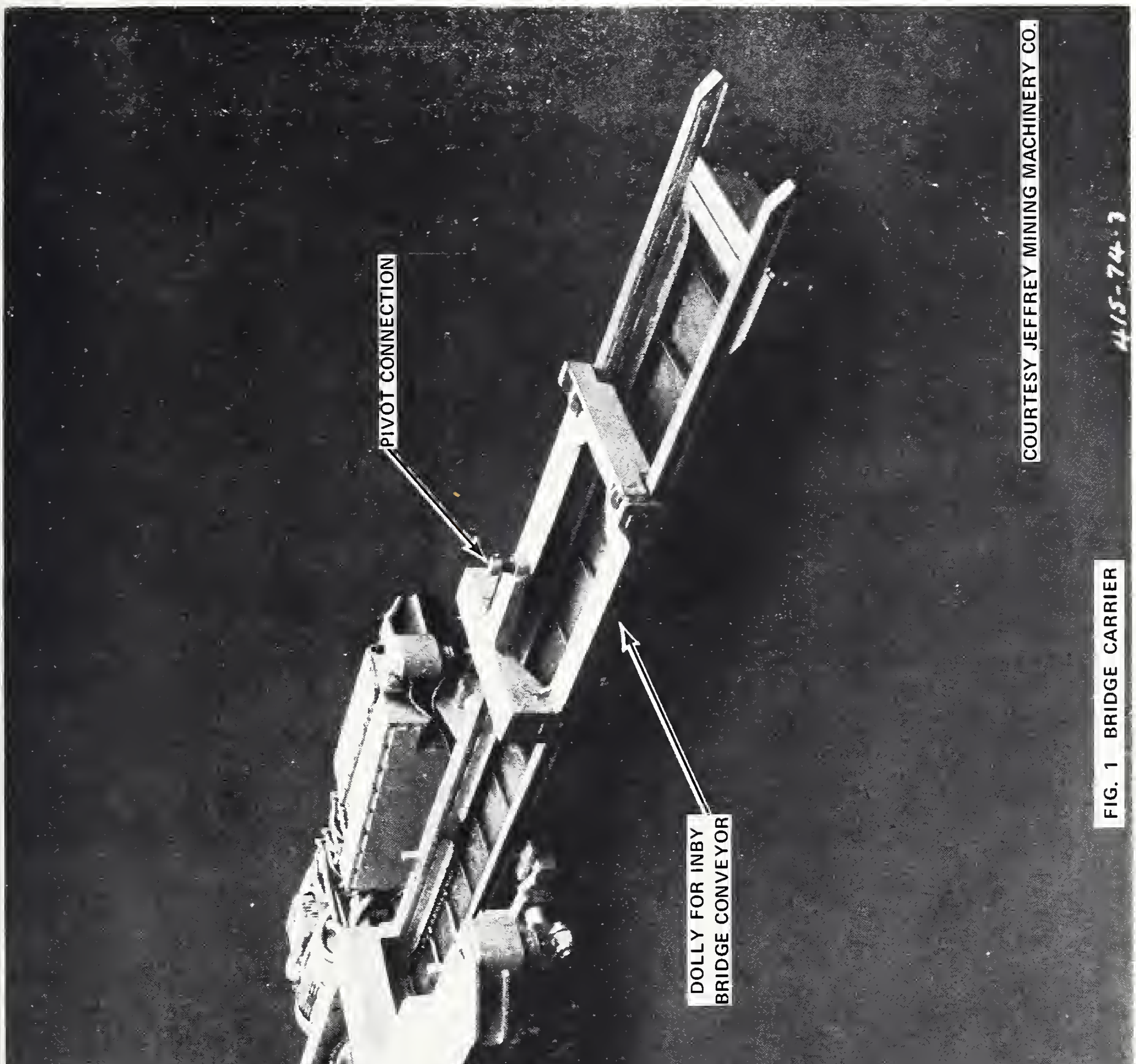


FIG. 1 BRIDGE CARRIER

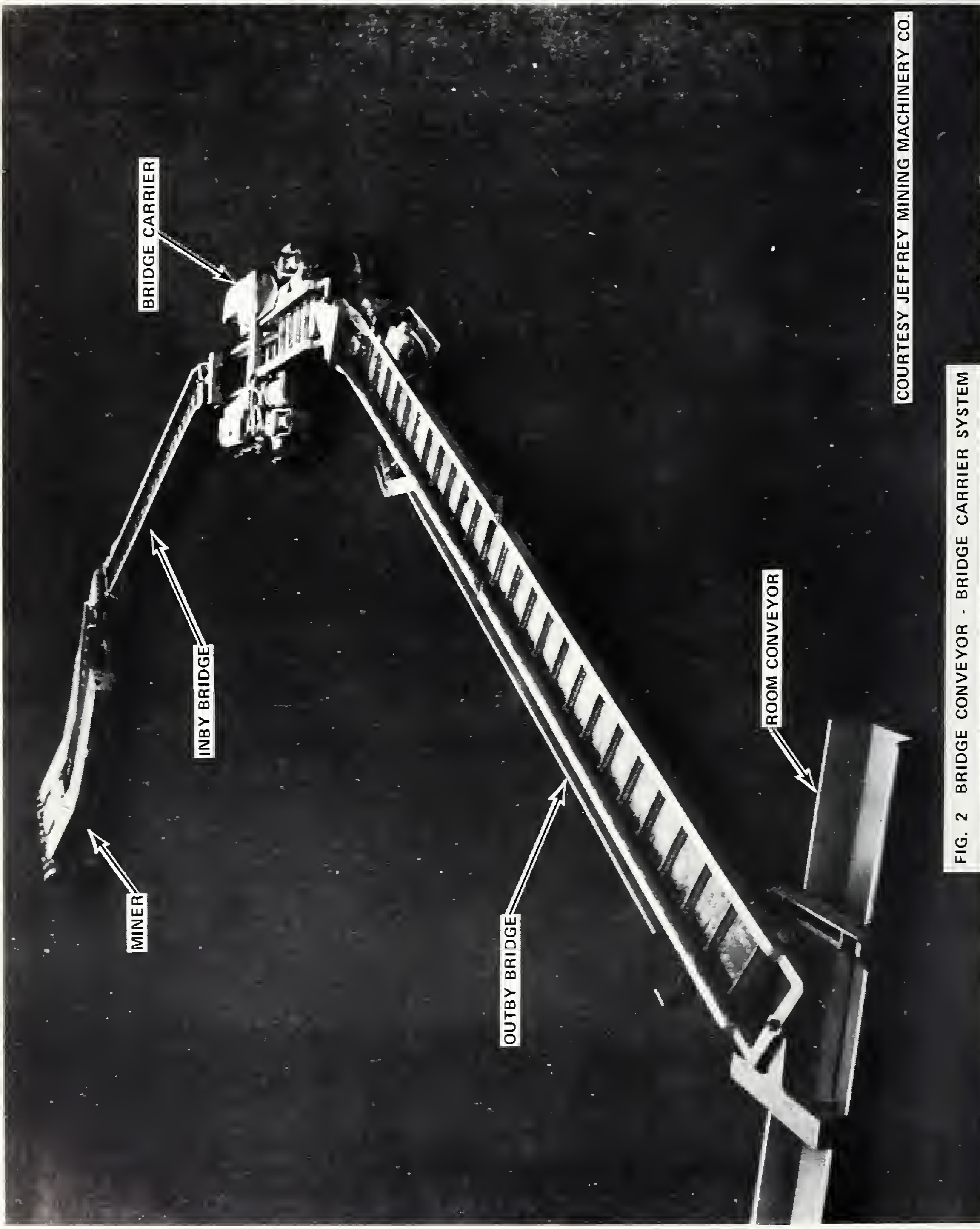


FIG. 2 BRIDGE CONVEYOR - BRIDGE CARRIER SYSTEM

conveyor, 20 feet of which is supplied by the miner. This reach becomes approximately 200 feet with a 5-unit system. Figure 3 shows the side view of a two-carrier three-bridge arrangement. Figure 4 shows a plan view of this system in a typical 5-entry mine development.

Starting at the miner, the miner tailpiece supports the inby end of a bridge conveyor. The outby end of this conveyor is supported on a dolly that rides for several feet along the inby end of the bridge carrier. A second bridge conveyor spans the gap between the outby end of the carrier and a dolly that rides on the side frames of the panel belt. Figure 5 shows the design of the transfer point and the pivot connection between the bridge carrier and the outby bridge.

In action the material goes from miner to first bridge to carrier to second bridge to panel belt. As the miner moves forward or backward, the carrier operator observes the motion of the supporting dolly on the inby end of the carrier. He moves the carrier so that the entire haulage system follows the direction of the miner.

The maneuvering of the bridge carrier to follow the miner takes a lot of training, particularly if two bridge carriers are used in the system. It takes a good crew about three months to become proficient.

The mechanical design of the bridges and the carriers has been refined over the past several years to the point where they now represent quite reliable products for the mining situations that are adapted to their use.

Certain physical characteristics of a mine, however, can cause severe operating problems for bridge carrier systems. Among these are the following:

1. Very wet bottom conditions.

2. Large quantities of broken rock coming off the roof or the floor.

3. Abrupt undulations in the coal seam.

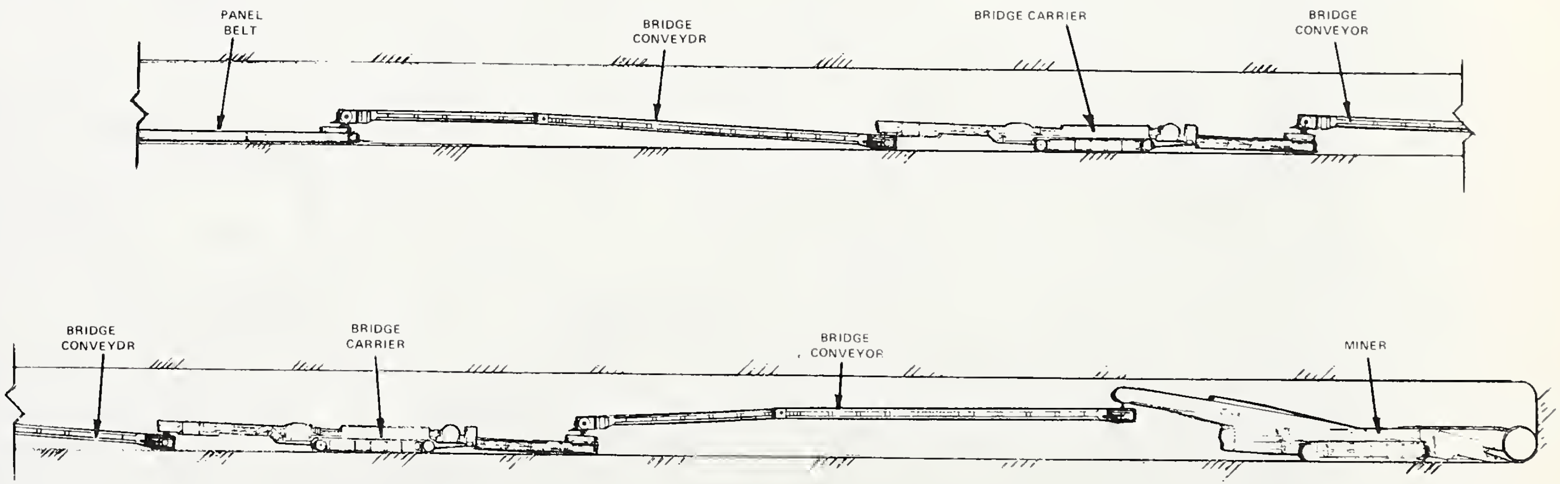


FIG. 3 SIDE VIEW OF TWO-CARRIER THREE-BRIDGE CONVEYING SYSTEM

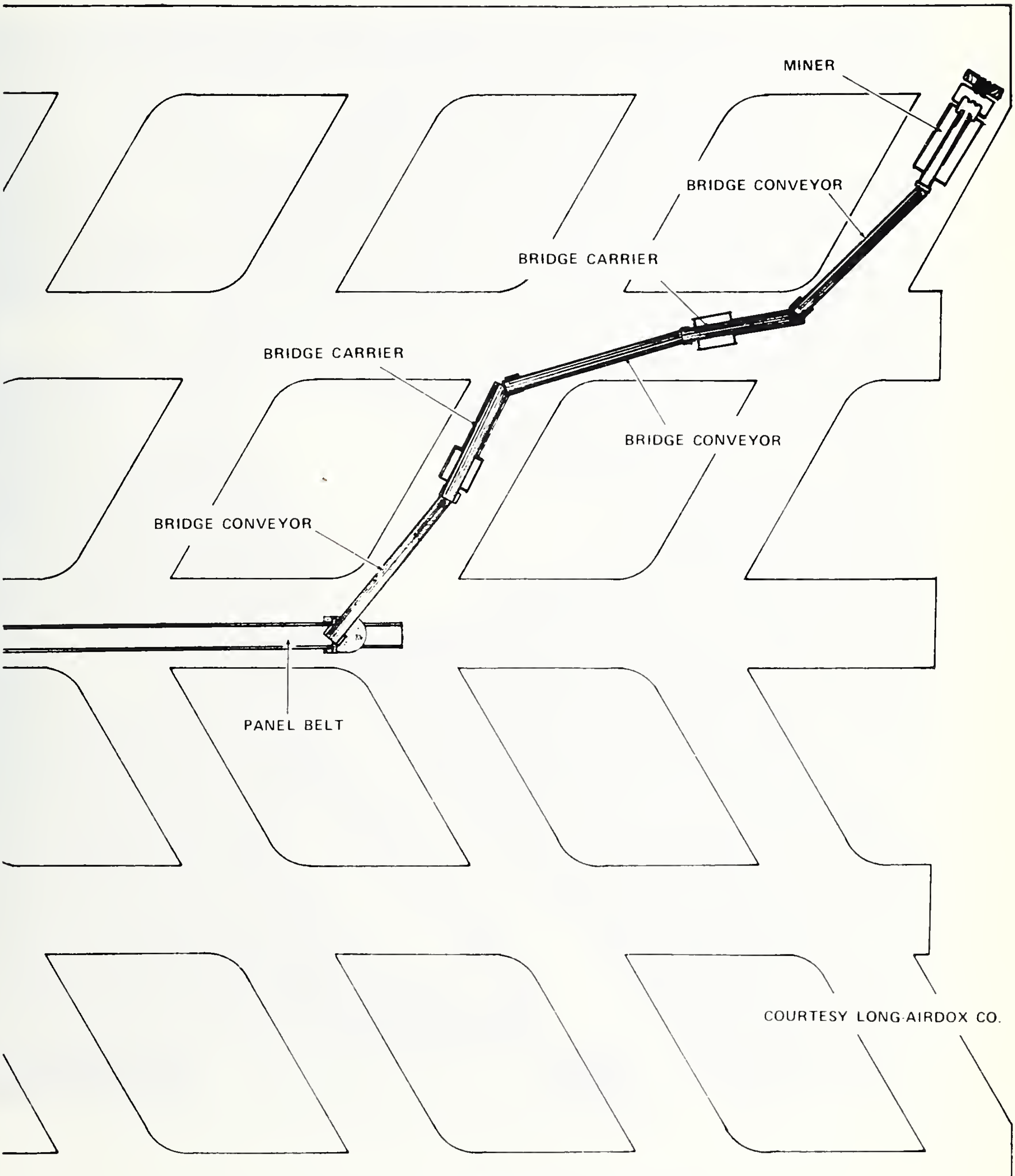


FIG. 4 PLAN VIEW OF BRIDGE CONVEYOR - BRIDGE CARRIER SYSTEM

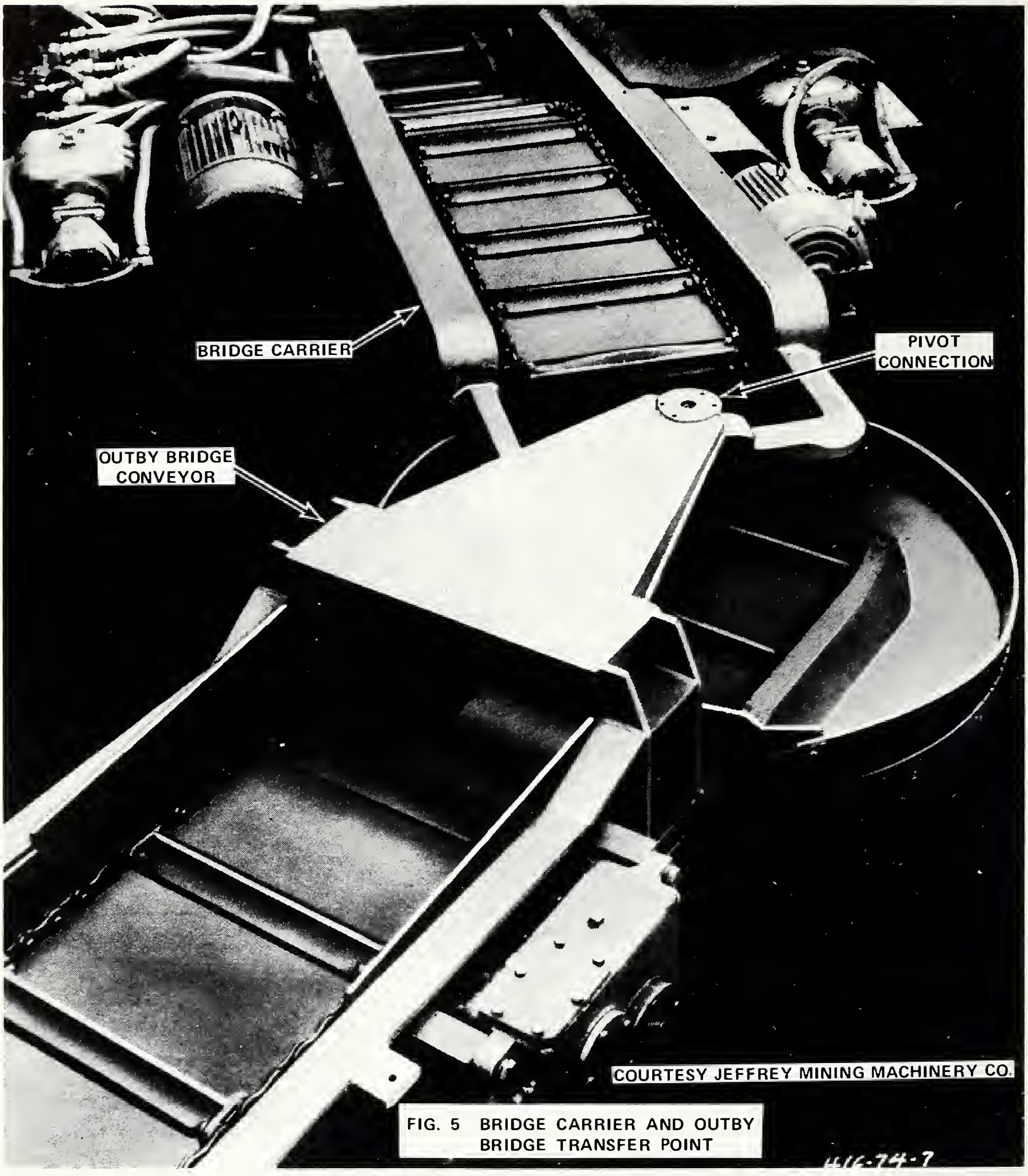


FIG. 5 BRIDGE CARRIER AND OUTBY BRIDGE TRANSFER POINT

In wet conditions there is an obvious traction problem, but in addition there can be an accumulation of wet coal and clay underneath the load-carrying part of the belts, which can eventually force a shut-down to allow for clean-out.

If large pieces of rock or coal are discharged by the miner they will eventually block the flow of material at the transfer points. This results in spillage and a shut-down to clear the blockage. Where this problem has been severe, consideration has been given to the design of a special feeder-breaker unit for use between the miner and the bridge conveyor system. To our knowledge, however, no such unit has been built and put into service.

Abrupt undulations in the coal seam, particularly in low coal, can impede the movement of the long bridge conveyor sections, which tend to get wedged against the roof or the floor of the mine.

For tunneling and surface mining applications, much longer versions of this system can be visualized, where reaches of 400 feet or more could be achieved with essentially the same design concept.

General Considerations Regarding Monorails

Since the last four conveyor systems to be included in this discussion are monorail-mounted, some general consideration of the monorail seems to be called for.

The additional work and expense involved with installing a monorail would appear to be the primary objection to haulage systems that require monorail support. Usually an additional roof-bolting device and a crew of two men must be added to the section crew. The expense of the additional bolts and the cost of the monorail sections and switching units are other negative factors where this type of haulage is considered.

On the plus side, once the monorail is installed, it is usually an efficient, trouble-free system. The rail sections are relatively easy to handle, to put up, and to take down for re-use. Long stretches of bad roof may prevent the use of a monorail, but occasional areas of bad roof can be circumvented by using beam supports instead of roof bolts.

Another factor in favor of a monorail system is the low drawbar effort required to move the conveyor system plus the load of material along the rail. This is in the order of 25-30 lbs of force per ton of suspended weight, compared to an order of 250-300 lbs of force per ton to move a ground-supported system where wheels or crawlers ride on the mine floor.

Monorail-mounted Transfer Conveyors

This type of conveyor has recently had a limited application in underground coal mines, having been used as a part of the overall conveying system for a few shortwall mining situations.

These installations have been straight belt conveyor assemblies designed to hang from trollies that ride on a roof-supported monorail. The length may range from 100 to 200 feet, and the monorail conveyor is arranged to ride back and forth immediately above a floor-supported panel belt that is in the maingate entry of a shortwall panel. This is illustrated in Figure 6.

The supporting frame of the monorail transfer conveyor is made up of straight rigid sections that are about 16 feet long. These are pinned together in series so that the conveyor assembly can adapt to a certain amount of undulation in the mine roof. The supporting hangers for the conveyor frame are attached at the joints between frame sections. The rest of the conveyor design is fairly conventional, with regular belting running on sets of troughed idlers.

In one test installation, the inby end of the monorail belt was connected to the outby end of a wheel-mounted Flexible Conveyor Train by means of a bridge conveyor that also served as a drawbar to move the monorail belt. With this system, the FCT had the flexibility to follow the miner around the corner and across the shortwall face, and the monorail belt handled the transfer of the coal to the panel belt. Since the monorail belt ran directly over the panel belt, it could discharge directly onto the panel belt throughout the length of its horizontal travel.

Since this type of conveyor is essentially a straight line device that cannot convey around corners, it has a limited use, but it may have an application in long, straight tunnel projects.

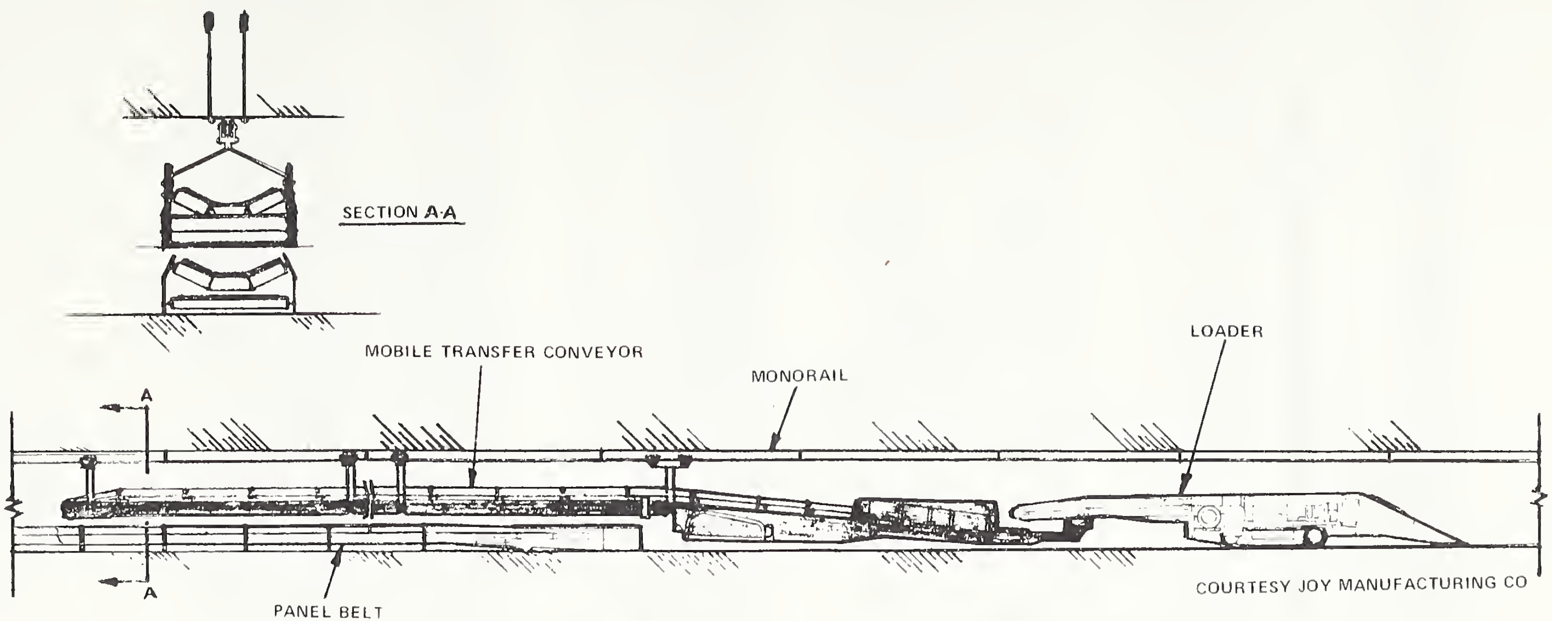


FIG. 6 MONORAIL-MOUNTED TRANSFER CONVEYOR

If conveying with such a device around a bend is a requirement, the systems described in the following sections may be useful.

Monorail-mounted Bridge Conveyors

This haulage concept has not yet been built, to our knowledge. It is currently the subject of a Bureau of Mines Request For Proposal (RFP) to qualified manufacturing companies.

The Bureau of Mines drawings show a string of cascading 40 foot long bridge conveyors that are designed to hang from a roof-supported monorail. The original idea is that the inby end of the system will be attached directly to the discharge conveyor of a continuous miner. The inby bridge conveyor thus acts as a towbar between the miner and the monorail conveyor. The outby end of the conveyor string rides directly over a floor-mounted panel belt in the center entry, so the roof-hung system discharges onto the panel belt.

With five bridge conveyors in series, the system has a reach of about 200 feet from the face to the end of the panel belt, and a capability to convey around one or more corners. The monorail is installed in the center entry, with side branches of the rail running out along the crosscuts through switching units.

Each 40 foot bridge section loaded with coal is expected to weigh about 4 tons.

This is an interesting concept that would appear to have a lot of potential. It is simple and relatively inexpensive, flexible, and seems to meet most of the requirements for underground continuous face haulage.

The preliminary Bureau of Mines prints show the system installed in a minimum seam height of 40 inches. The bridge conveyors are shown with conventional rigid side frames, with the belts running on shallow troughed idlers. Each bridge conveyor belt has an independent electric motor driving through a gear reducer.

When the final designs are made for this sytem, the transfer points will need to receive a lot of attention so that a smooth flow of coal can take place from one conveyor to another. The length and width relationship on the individual conveyors and the support to the monorail will have to be designed so that the chain of elements can be moved around several corners without interfering with the mine ribs.

It may be worth considering using a surge car in this system, which would follow behind the miner and serve as a feeder and a tow for the monorail conveyor system.

Monorail-mounted Serpentix Conveyors

The Serpentix conveyor, and the Flexible Conveyor Train that will be described in the following section, are continuous belt conveyors that have a capability of operating along a changing, winding path. This is opposed to conventional belts that only operate on a straight line, and to conveyors that are designed to operate only around a fixed turn.

The Serpentix conveyor was originally developed in Germany, and is made in the United States by Serpentix General Corporation of Denver, Colorado. Joy Manufacturing Company has acquired the rights to make the Serpentix General Corporation product for use in underground bedded deposits. The latest Joy Serpentix products have a considerable number of design improvements that have been engineered by Joy.

At the present time the Peabody Coal Company is the only company operating Serpentix conveyors in underground coal mines in the U.S. Peabody has about four years of operating experience with their original installation at their #10 mine near Taylorville, Illinois. They have operated a second installation briefly at their Deercreek mine near Huntington, Utah, which has recently become the property of Utah Power and Light Company. A third installation is to be used at Peabody's Baldwin #1 mine near Marissa, Illinois.

The system in use at Peabody includes the following equipment, beginning at the inby end: (Please refer to Figure 7.)

1. Tram car. This also serves as a surge car behind the miner.

2. Bridge Conveyor. This also serves as a drawbar between the tram car and the Serpentix conveyor.

3. Monorail system. The monorails are fastened to the roof with conventional roof bolts, and the system includes switching devices at crosscut intersections.

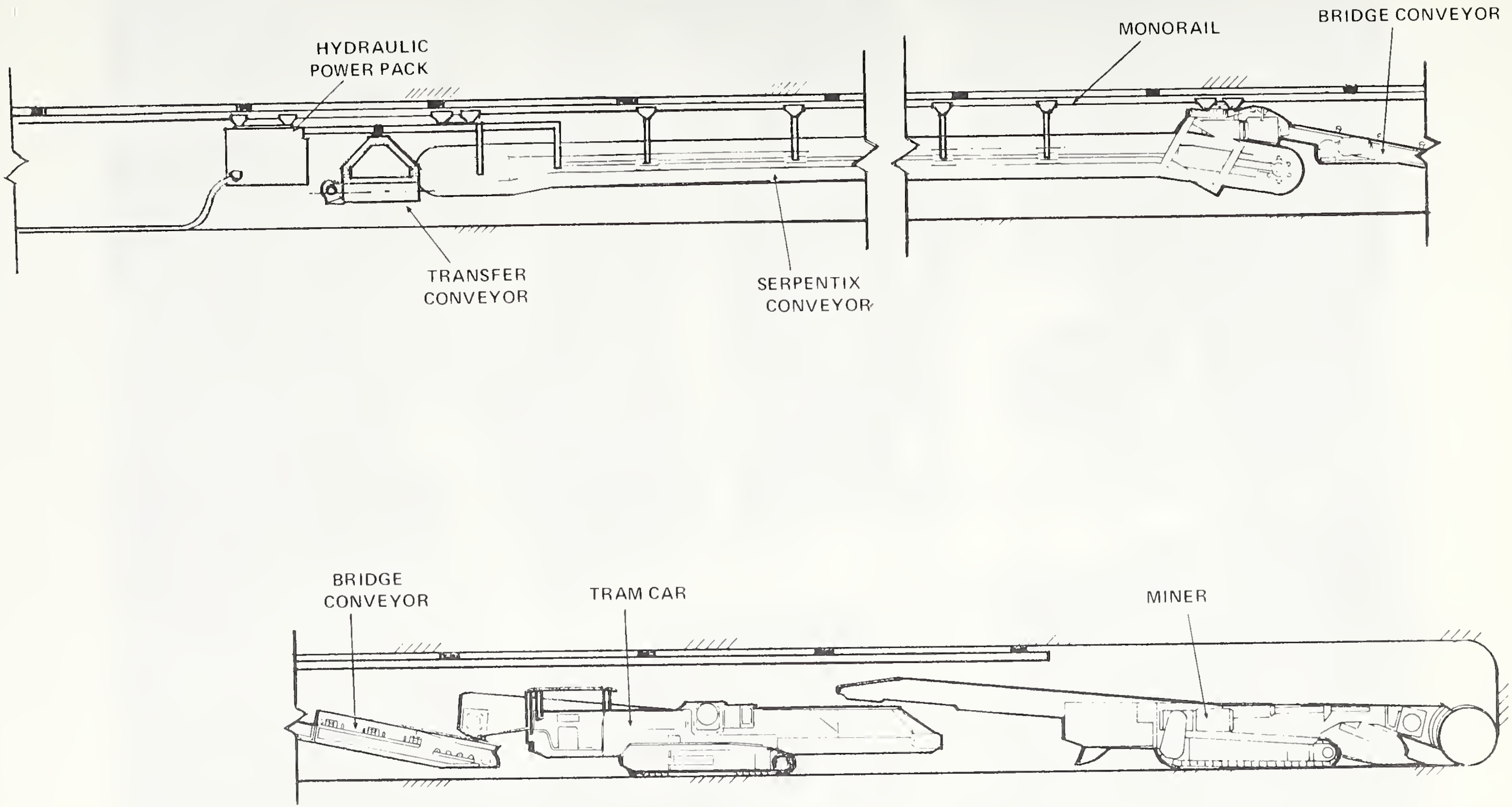
4. Serpentix conveyor. This is supported from and movable on the monorail. Lengths range from 200 to 400 feet.

5. Transfer conveyor. This is located at the outby end of the Serpentix to transfer coal to a panel belt which is set up parallel to the main monorail track.

6. Hydraulic power pack. This is also supported from the monorail, and connected to the Serpentix with a short drawbar so that they move together. It provides power to the Serpentix belt and to the transfer belt.

7. Panel belt. This is a 36 inch wide conventional rope-supported belt. Belt is added and the tail-piece is advanced as required.

The Serpentix belt is a series of molded neoprene pieces that are bolted together at bracket locations at eight-inch intervals along the conveyor drive chain. Each neoprene piece has a convolution, or hump shape, molded into it that runs the width of the belt. The space between humps of adjacent neoprene pieces forms a pan, and the convolutions allow for the flexibility required in the belt assembly when it goes around a turn or over a pulley.



COURTESY JOY MANUFACTURING CO.

FIG. 7 SERPENTIX CONVEYOR
SIDE VIEW

The belt and the drive chain are supported by roller carriages that ride in grooves of a flexible vertebrae spine assembly that is hung from dollies on the monorail track.

Development work is still going on with the Serpentix to improve the reliability and service life of the system. One of the more recent changes being considered is the replacement of every other eight-foot vertebrae spine section with a solid section, which would reduce complexity and cost and is expected to still retain enough flexibility for turning corners.

Present designs of the Serpentix require a minimum seam height of about seven feet.

Monorail-mounted Flexible Conveyor Trains

The Joy Flexible Conveyor Train concept is based on a molded troughed belt that has a capability to carry a load around a corner.

Joy Manufacturing Company and the B.F. Goodrich Company have been working together on this belt concept since 1968. Two complete systems, wheel-mounted to run on the mine floor, have been built and tested in underground coal mines during the past few years. These tests were not a complete success, since problems were experienced with the train of wheeled cars that supported the belt, and the belt design itself proved to need further development to improve its performance and service life. Figure 8 shows the wheel-mounted FCT, and Figure 9 is a closer view of the special belt.

A completely redesigned belt has recently been built by Joy and installed on a monorail for test under a Bureau of Mines contract. This installation is at the West Virginia Laurel Run mine of Virginia Electric Power Company. No results are available at this writing, but the monorail system should be a big improvement over the original ground-supported design, and the changes made in the belt construction are expected to provide marked improvements in performance and service life. Figure 10 shows the general arrangement of the monorail-mounted Flexible Conveyor Train.

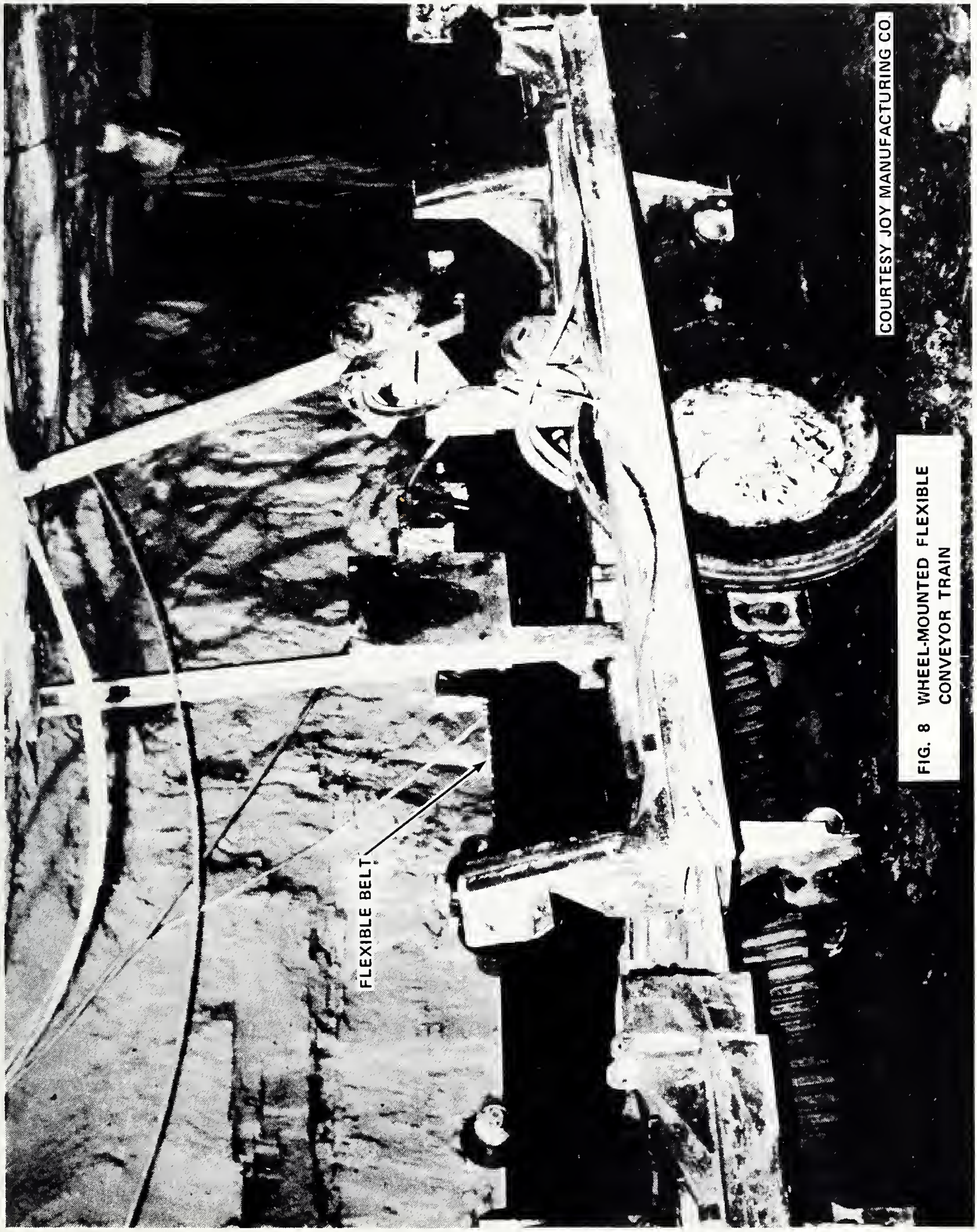


FIG. 8 WHEEL-MOUNTED FLEXIBLE CONVEYOR TRAIN

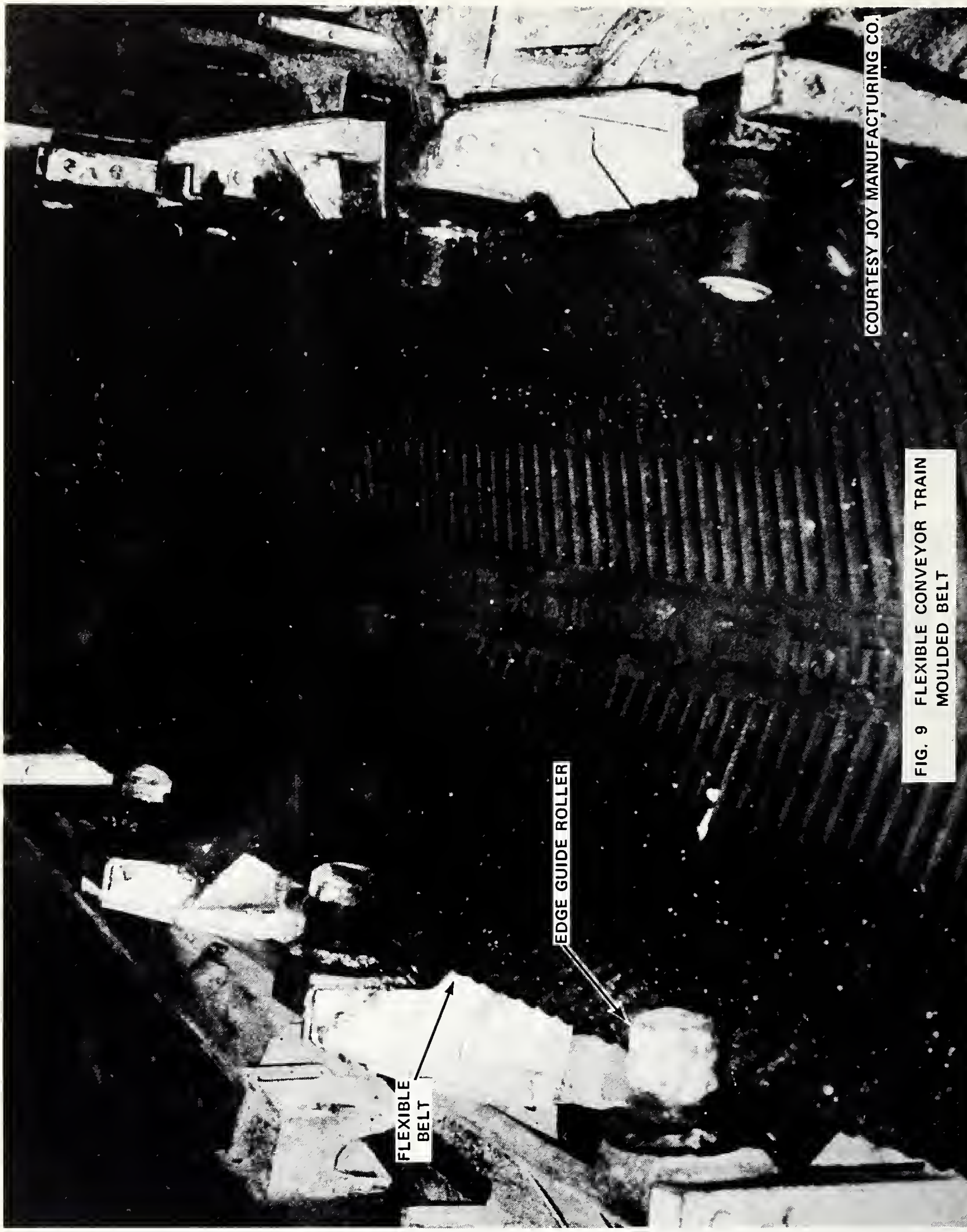
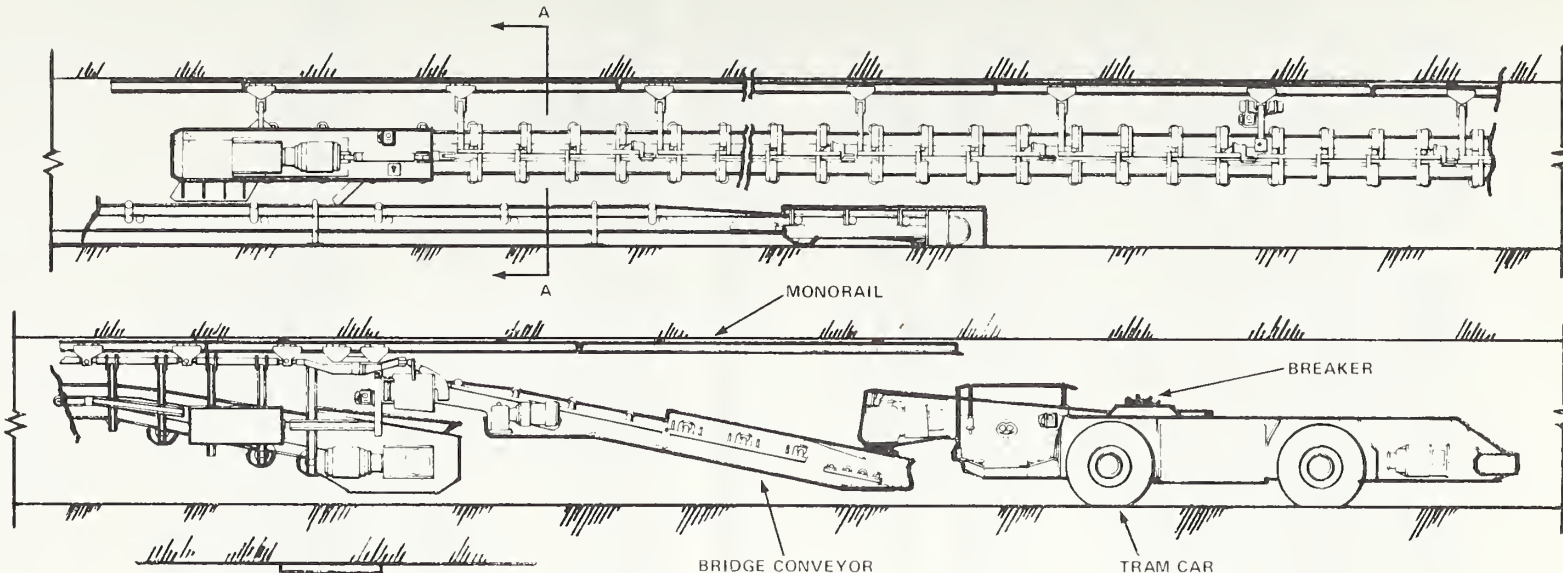


FIG. 9 FLEXIBLE CONVEYOR TRAIN MOULDED BELT



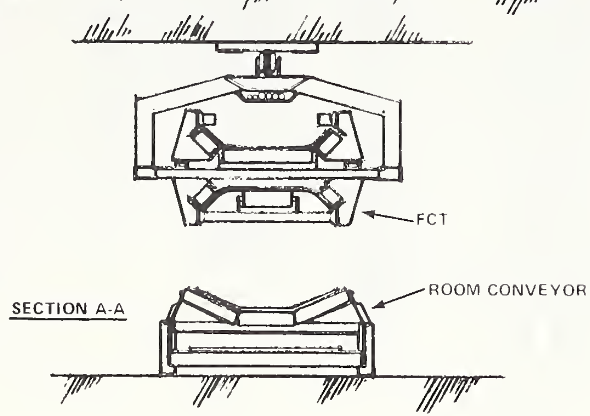


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FIG. 10 FLEXIBLE CONVEYOR TRAIN
MONORAIL MOUNTED

The monorail version of the FCT is connected to the miner by a bridge conveyor. This bridge, however, does not serve as a drawbar, but is connected to the inby end of the FCT conveyor by a dolly arrangement that allows the bridge to move several feet independently from the conveyor. Conveyor tramming is accomplished by electric motor drives that are called "mules". These consist of opposed sets of small polyurethane drive wheels that are spring-loaded against the web of the monorail. An operator stationed near the front of the FCT watches the movement of the bridge conveyor and controls the movement of the FCT by actuating the "mule" drive units from a remote control station mounted on the inby end of the FCT.

The outby end of the FCT rides directly over a floor-mounted panel belt, and discharges downward onto the panel belt through the range of its horizontal travel.

Like the Serpentix conveyor, this design of the FCT requires a minimum seam height of about seven feet.

Current Research and Development

The following brief notes describe some current research and development projects sponsored by the Bureau of Mines that are related to the conveying concepts discussed in this paper.

1. Auto-Tracking Bridge Conveyor Train.
   Contract HO 155157
   Foster-Miller Associates, Inc.

   This project includes the design, building and testing of a train of four wheeled bridges that will be automatically guided by an electric cable buried in the mine floor.

2. Multiple Unit Continuous Haulage.
Contract HO 155123
Jeffrey Mining Machinery Company

This project is for the redesign, build, and test of a machine that was made by Jeffrey in the early 1950's. It was called the Moleveyor at that time. It is a train of powered cascading conveyor cars that are guided at the front and rear of the train. The intermediate cars are designed to be self-tracking.

3. Remote Controlled Battery Operated Scoops.
Contract HO 155103
Westinghouse Electric

With this system the idea is that one man at the face, through remote control, will control the loading of several scoops that will then be guided to a discharge point by a system of electric cables buried in the mine floor.

4. Mechanized Unit for Extending Panel Belt.
Contract HO 357102
MB Associates and West Virginia Armature.

This project calls for the design of a 4-wheel work vehicle which will allow a speedup in the job of extending or shortening a panel belt. The goal is to make a 100 foot panel belt extension in 20 minutes, using four men and the subject work vehicle.

The vehicle will be designed to do the following things:

a. Store a roll of belt.
b. Store a roll of belt support cable.
c. Store rope supports.
d. Provide power tools to speed belt assembly or disassembly.
e. Pull the tail section.
f. Provide tensioning means for the support cables and the belt.

5. Serpentix Conveyor on a Shortwall Face.
(Cammoy System)
Contract JO 166042
Ledgemont Laboratories

This project involves the use of a Serpentix conveyor suspended from the front of the chocks along a shortwall face.

6. Extensible Bridge Conveyor System.
Contract number not known.
Battelle Institute and Ingersoll-Rand

This contract involves the design of a mobile bridge conveyor that has the capability to extend its length by means of some telescopic mechanism. These machines would be used in series to form a conveying system.

PAPER 8

Hydraulic Transportation for Coal Mining

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HYDRAULIC TRANSPORTATION FOR COAL MINING

by

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Because the current Bureau of Mines research program has been limited to the adaptation of hydraulic transport to underground coal mine haulage systems, this discussion will be limited to this area with little extension to tunneling. Coal seams in the Eastern United States are usually mined in a rectangular opening 16 to 20 feet wide and with heights beginning at 28 inches. Seventy percent of the coal mined underground comes from mines with seam thicknesses of 4 feet or less, and to further complicate the haulage system, operations require that several working faces be maintained for sufficient production and to maximize the efficiency of the mining machines. When several sections of these multiface systems are in operation, haulage in coal mines becomes a very complicated network.

Another factor that makes coal mine haulage difficult is that the presence of fine coal dust and methane gas creates explosion hazards which require special consideration. A separate haulage entry with particular ventilation requirements must, by law, be maintained. This constant danger creates additional manpower demands and increases the cost for rock dusting, cleanup, repair work, and safety checks.

Because of all the delays in current coal mining methods and the lack of truly continuous face haulage systems, there is great variation in the output of coal from continuous miners and yet the haulage system

must cope with it. The mining capability of a continuous miner ranges up to 15 tons per minute, but it is cutting coal only 60 to 80 minutes of the shift owing to inherent delays in the system. Some of the delays are necessary. For example, miners may never work under unsupported roof; therefore the mining machine must back away from the face about every 20 feet to allow the roof to be bolted. Of the delays that are not required, waiting for the haulage system is the greatest. It has been estimated that development of a reliable continuous face haulage system could increase coal production 40 percent in room-and-pillar mining.

Coal is of low density and is relatively soft and uniform throughout the seam. Usually, little hard rock is cut. "Run-of-mine coal" contains some of this mine rock and some clay and has top-size particles of 4 inches or more. By contrast, tunnel muck is much heavier and varies greatly in hardness.

There are many potential benefits for improving the production, productivity, and safety of coal mining. It is anticipated that production will be improved by development of the continuous face haulage system, which would eliminate many of the waiting delays common to current haulage systems. Productivity could be increased by fully automating the hydraulic haulage system and by reducing man-wasting operations such as rock dusting and cleanup work. Safety will also be greatly improved by removing hazards such as trolley wires, trailing cables, vehicular traffic, and dust generation away from the face.

The Bureau of Mines has been involved in hydraulic transport since 1950 on both overland slurry transportation and underground hydraulic haulage. Thus far more than 20 publications have been produced and 11

contracts funded for such work. A listing of available reports is given in the Appendix (A1-A27) along with some other useful references. In the past 4 years, a comprehensive program has been in progress to develop systems, engineering data, and equipment to encourage the use of this haulage method. The program will be described in more detail later.

Some History

Hydraulic transportation is a materials handling system that has been around for a long time but has never been adequately utilized. Fluming as a haulage system probably originated when some cavemen saw a flash flood wash rocks, trees, and dirt down a valley. The first engineered closed-conduit system on record is of jet-pumped gold mine hoists that lifted gold-bearing gravel as much as 55 feet to sluice boxes in the 1850's in California. U.S. Patent No. 277,762 was granted to J. H. Martin for this use in 1873. The first U.S. Patent for hydraulic transport in pipelines was No. 449,102, granted to W. C. Andrews in 1891. The first commercially operated coal pipeline was built in 1914 by G. Bell, an English powerplant engineer. For 10 years, his system transported 50 tons per hour of 5-inch top-size coal over a distance of 1,750 feet through 8-inch cast iron pipe. He used a 7-inch pump with a 50-hp motor and operated at a concentration of 50 percent and a velocity of 4 feet per second.

Interest in hydraulic transport has ebbed and flowed with the tide of the economy. The literature shows a flurry of interest in the 1940's, and in the 1950's significant technical progress was made in several countries through a strong research effort. Foremost in this effort were Durand, Condolios, and Chapus of France. A good deal of experimental work was conducted in Great Britain at full scale in the late 1950's,

and experimental work was in progress in the Netherlands, Poland, and the U.S.S.R. During the 1960's, many nations became involved in developing hydraulic transport for mining, and a number of coal mine haulage systems were installed, as shown in Tables 1 and 2. These tables are a listing of coal mine haulage installations only, which have been reported in various publications. No attempt has been made to record similar data for other minerals because of time and program limitations. Some operations may be missing, and the dates shown are those of the publications, which generally do not indicate the date of startup. Later publications seldom indicate whether such installations were still in operation. Frequently, data are omitted, as indicated by the number of dashes in the table. The primary benefit of these lists is to show the continuing worldwide interest in the pipeline transport of large particles for coal mining.

Current Status

In this decade a new surge of interest in hydraulic transport has become evident. Vast overland coal pipelines are being planned, partly because of the success of the Black Mesa Pipeline and partly because of the advantages of minimal environmental disturbance and resistance to cost escalation. New research and development facilities for coarse particle transport are being built, as indicated in Table 3. More seminars are being held and more papers published than ever before. Interest in all aspects of slurry transport is evidenced by two international conference organizations which hold regular meetings, the British Hydromechanics Research Association (BHRA) in even-numbered years, and the Slurry Transport Association (STA) annually. Attendance ranges from 200 to

300 (A33-36, A40-A41). The advantages in improved safety and the potential for increased productivity have become evident. Perhaps now the problems of this mode of transportation will be resolved and haulage systems will be built with knowledge instead of nerve.

A number of areas of hydraulic transport that are familiar in varying degrees to engineers are summarized in the following paragraphs.

Long-distance overland slurry transport. - This field is fairly well known to designers and novices because of extensive research and wide news coverage of large installations. In general, a slurry pipeline becomes more economical than rail haulage when significant lengths of upgraded or new track are required, when a cross-country route is significantly shorter, or when terrain is too rugged for railroads. Because fine grinding of the transported material is required to achieve low transport velocities with minimum settling and pipeline erosion, preparation and separation costs are very high - up to 40 percent of the capital cost of the pipeline. The environmental aspects of pipeline transport are very good, but in the United States there currently are problems in obtaining the right of eminent domain and water supplies. Eminent domain probably will be resolved in the next few years, but the water problem will be especially difficult in the West.

Fluming. - Material can be easily flushed downslope in troughs by water. With modern plastics, slopes can be as little as 4 degrees. Wear is a problem because there is no suspension. Flumes obviously cannot be used on upward slopes.

Dredging. - A fairly well developed technology with a long history. Pumps have been developed with good wear resistance and ability to pass

particles up to 75 percent of the pipe diameter. However, dredge pumping is usually done with solids concentrations of less than 20 percent, and pumps normally can provide suction adequate for working depths of only 100 to 150 feet. A recent advance has been made by adding a jet pumping system at the end of the suction pipe, which increases working depths to over 200 feet.

Marine mining. - This is essentially dredging at great depths, but the field is in its infancy. Interest is high because of the quantity and value of sea-floor minerals. Depths of 15,000 feet are being considered, but the technnique has not yet been developed.

Capsule pipelining. - Research work has resulted in fairly well defined design parameters, low energy requirements, and good injection and separation systems. However, packaging and unpackaging of granular solids remains such a problem that this technique is little used for bulk handling.

What Are The Problems?

Engineering Design Data

The largest problem is the lack of engineering data for the design of systems. Data have been accumulated for both fine- and coarse-particle transport, but virtually all of it is kept as proprietary information. For large particle transport, the theory is quite complex and little has been accomplished in making design data generally available. Fine-particle transport theory is simpler and more widely published.

Crushing the solids to fine sizes is undesirable for both mining and tunnel excavation because of the cost for crushing at the origin and

for dewatering at the destination. Thus, accurate data for transporting large particles have become increasingly desirable. "Large particles" is a relative term, but they can be considered as larger than about 1/8 of the transport pipeline diameter. Since most granular solids have a distribution of particle sizes, the terms concerning particle size commonly refer to the top size of the distribution.

Oversizing of pump drives for conservative design is usual but can be very expensive, and lack of knowledge about plugging can make the system risky to operate. In the past, the lack of good solids-injection equipment, despite much effort, has significantly retarded the adoption of hydraulic transport.

The effects of particle size, high transport concentration, and their interaction are very poorly understood. Most production installations and research work on coal have involved at moderate concentration levels of 30 percent by volume or less, and maximum particle sizes of one-fourth of the pipeline diameter or less. This probably is from fear of plugging the pipeline, which can not be tolerated in a production installation and is frustrating and time consuming in research work. Most existing data indicate that headloss increases as concentration increases up to about 30 percent. Headloss also increases with particle size, but a large contribution to this headloss is due to the higher transport velocity required to keep the particles in suspension. Above 30 percent, the available data do not show clearly the rate at which headloss increases, but a small amount of evidence indicates that the increase in headloss may level off or even decline under certain conditions.

Perhaps phenomena occur that are similar to those of "dense-phase" pneumatic transport wherein solids can be carried at half the transport velocity of dilute-phase transport. Any increase in concentration, while maintaining reliable operations, would significantly improve the efficiency of pipeline haulage systems.

Equipment

The next problem area is equipment such as pumps, feeders, crushers, separators, pipelines, and instrumentation.

Pumps

Many coarse-particle transport systems use centrifugal pumps to ingest premixed slurry and to boost pressure at intervals along the pipeline. Centrifugal pumps have either closed, semi-open, or recessed (vortex) impellers. Among the three types, the closed impeller provides the highest efficiency but it has the smallest passages and the worst wear problem. The situation is just the reverse for the recessed impeller. The semi-open impeller provides an intermediate solution to these problems. The worst part of the problem with pumps is that the actual efficiency of performance is known accurately only for water and for some fine-particle slurries. No data are available for coarse-particle slurries. Present guesses are that clear water efficiency may be reduced by as much as 70 percent for a particle size of 1/3 pipe diameter. Because even a 5-percent improvement at this level would be significant, research work is needed. Wear in centrifugal pumps can be reasonably well controlled by using linings such as rubber, urethane, and Ni-Hard.

Pressure head capabilities have gradually increased to levels of over 500 psi through improved design. In the Soviet Union, a two-stage pump has been developed which is a significant advance (if plugging and particle attrition are not excessive), but little information is available. Attrition is a serious problem in centrifugal pumps, especially if the solids are brittle and the pump has a hardened lining. A rule-of-thumb is to keep the impeller peripheral speed at 100 fps or less, but "rules-of-thumb" are not good design tools. Research work is needed in all these areas to provide manufacturers with specific requirements.

Other types of pumps seldom can be used in coarse particle pumping because of plugging and wear problems due to the small internal clearances in valves and seals. Piston pumps are used for overland slurry transport because their desirable operating characteristics and high pressure capability (2,000 psi or more) minimize the number of pumping stations required. The fine particle sizes used do not clog valves or seals as would the coarse particles in run-of-mine coal haulage systems. It would be possible to use piston pumps for coarse-particle transport if the coal were injected into the pipeline downstream of the pump. However they are physically large, which mitigates against their use in the confined space of underground operations.

Feeders

A number of feeders are available for feeding coarse-particle slurries into pipelines. However, most of them are too large for thin-seam coal mining needs. It is possible that "pipe feeders," such as the ones marketed by Hitachi and Transflux International, and rotating-pocket feeders, such as those made by Kamyr Corp., could be used in tunnel-muck haulage systems. The British spent considerable effort in

testing various feeder designs involving pistons, rotating plugs, and pockets in the 1950's and 1960's but abandoned them because of particle attrition, wear, and leakage problems. It is possible that some of these designs could be revived because of the advances in materials engineering since then, but the benefit would be doubtful. The Soviet and the Polish Governments each developed their own feeders, primarily for hoisting, at about the same time. The foremost of these were large pressure vessels with lock-hopper feeding or sealed-screw feeding. Because of their size, however, they required much excavation and complex auxiliary equipment. A number of other concepts such as a portable sealed-screw feeder were mentioned in the literature, but it is not known if they were ever used.

The lock-hopper system received much attention and was used at the Devillaine Colliery in France for several years. A lock-hopper system incorporates two chambers sealed from each other and from both pipeline and atmosphere by valves or sealing doors. Feeding is accomplished through a sequence of filling the top chamber, sealing it off, equalizing the pressure with the lower chamber, opening the valve between them so the solids can drop into that chamber, closing that valve, and then opening the bottom valve while exhausting the top chamber for a new cycle. Several sets of these lock-hoppers can be arranged to operate sequentially to provide a nearly continuous feed to the pipeline. The Bureau of Mines tested a lock-hopper system extensively during the 1960's, but was unable to achieve either reliable operation or concentrations over 17 percent, primarily because of the complexity and slow speed of the timers, relays, and valve operators. Undoubtedly with transistorized

printed circuits and computer control, much better performance could be achieved. The system remains cumbersome and physically large and is suitable only for shaft hoisting as a rule.

The pipe feeders previously mentioned can be thought of as horizontal lock-hoppers. The chambers (2 or 3) are pipes which are charged with slurry by a low-pressure centrifugal pump. By properly timed operation of valves, the charged pipe is connected to a high-pressure pumping system which pushes the slurry into the pipeline. Sequencing the chambers provides a fairly uniform feed of slurry to the pipeline. While pipe feeders can be made low in height, they are 50 to 150 feet long.

Continental Oil Corp. and its subsidiary Consolidation Coal Co. have developed a feeder that is capable of following a continuous miner in a 6-foot coal seam. It is primarily a centrifugal pump with a water-filled feedbox attached to the pump intake. By accurately controlling the water level, coal can be fed into the tank where it is drawn with water into the pump. Control of the coal feed and waterflow sets the solids concentration in the pipeline.

Crushers

One disadvantage of hydraulic transport is that maximum particle size must be controlled to suit the pumps and pipeline. Conveyors can carry substantially larger particles, and rail and truck are almost unlimited in the lump sizes they can carry. In coal mining, crushing is difficult to accomplish because the physical size of crushers capable of handling miner output is too large for most coal seams. Consequently, breakers have been developed which attach to a feeder vehicle and crack

larger lumps as they are fed into the haulage system. Because of the configuration of the breaker, which is a row of spaced pick wheels, "finger-shaped" pieces can sometimes get through unbroken. Some control over particle size is exercised by the continuous miner operator's technique with the machine, but primary control still must be by way of crushers or breakers.

Crushers also generate dust. The generation of dust in a coal mine creates both a health and a safety problem, so the concept of crushing is undesirable for coal mining unless the coal can be thoroughly and reliably wetted.

Conoco/Consol has achieved size control by developing a roll crusher which is submerged in their feedbox.

It would seem that the crushing of tunnel muck should be a less difficult problem because of the lower hazard level from the dust and because more space is generally available.

Separators

This equipment is used to separate the solids from the water. The engineering design of separating equipment is a fairly well-defined science with a wide variety of types available for the removal of the different size fractions. The approximate capabilities of the various units are -

	Particle size, μm	Feed, % solids
Screens	+ 200	7 - 40
Sieve bends	+ 500	0 - 40
Cyclones	5 - 500	4 - 40
Thickeners	5 - 500	0 - 30
Filters and centrifuges	0 - 8,000	0 - 80
Dryers	5 - 10,000	60 - 100
Settling pond	+ 5	0 - 60

The selection of the type of separator to be used will depend largely on the pollution control standards of the local area, but it should be kept in mind at the time of selection that the trend is toward tighter standards.

For application to underground coal mining or tunnel excavation, however, there are two big disadvantages to all of this equipment. Because of the volume of coal and water to be handled, the separator system must be physically large, and because most separators depend on gravity in the process, the vertical height is likely to be excessive. The second factor is their cost. The finer the particles to be removed, the higher the cost.

The only practical solution to the first problem is to do the separating on the surface rather than underground. The second problem, cost, can be reduced in the case of coal mining by savings from the reclamation of coal fines. In the case of tunnel muck, the cost can be justified only on the basis of preventing degradation of the surface environment.

Pipelines

The pipes are the least complicated part of a fluid transport system, but there are factors that must be considered. Some of the greatest advantages of pipeline systems are (1) they can operate as "add-on" systems, (2) they completely enclose the solids, (3) they have no moving parts, and (4) they can "shortcut" to the surface through boreholes from either mine entries or tunnels. No other haulage system is as flexible in this regard. Rail and rubber-tired equipment both have a minimum turning radius far greater than that of pipelines. Belt

conveyors are limited to lengths of about 5,000 feet and must be connected by transfer chutes, which also contribute to underground health, safety, and maintenance problems.

Unnecessary bends and dips in pipelines should be kept to a minimum to reduce opportunities for plugging. At low velocities, fines and slimes may accumulate in dips and remain a continuing maintenance problem. If dips cannot be avoided, a higher velocity must be selected, or provision must be made for cleanout in these areas. Coal is not abrasive, but the refuse in the coal and tunnel muck are, and quick changes of direction (as at elbows) will cause excessive wear.

The pipeline must be sized to provide sufficient capacity to handle production and at the lowest practical velocity to reduce energy requirements and breakage of the material. For underground coal mines, pipe lengths must be selected for handling around corners at the shaft bottom and in the entry. In tunnels, only the shaft-bottom turn must be considered. Victaulic or Dresser-type couplings are preferred for ease of maintenance, for extending the line, and to minimize flange-bolting time or underground welding. Corrosion control in hydraulic systems usually is easily and inexpensively achieved with lime or chromate additives.

Erosion of the pipe walls can be a serious problem. At present, it is expected that transport of the solids will be by "saltation" or "sliding bed" motion to avoid the excessive wear, attrition, power, and cost associated with high velocity. "Saltation" is a term used to describe the motion of particles which roll and bound along the bottom of the pipeline when the fluid velocity is too low to completely entrain them. "Sliding bed" describes the motion at a velocity lower than for saltation, in which a layer of material on the bottom of the pipe is

moved en masse by the force of the flowing fluid. These two modes of transport cause the pipe wall to wear thin in a period of time which is dependent on the abrasiveness of the solids. Presently, this is combated by rotating the pipe until it is uniformly thin and then replacing it. Improved pipe materials and linings are being developed which will reduce erosion problems and costs. Among these are plastic pipes and basalt, urethane, and hardened-steel linings.

Leakage or rupture of hydraulic pipelines has more serious consequences underground than in surface systems. Therefore, safety features must be designed into the system. Pressure sensors or flow sensors should be attached in strategic locations and set to shut down the pumps and feeders if the line pressure or flow should fall by a preset amount, which would indicate a large leak. Emergency clamp-type seals should be readily available to close smaller leaks until the system is to be cleared of solids and shut down.

In the case of hydraulic hoists in deep shafts, safety measures must be given careful consideration because of the high pressures involved, even when the pump is shut down. An elementary precaution would be to separate the pipeline from a surface water supply to prevent siphoning into the mine or tunnel. In the case of an emergency shut down, it is recommended that a sump should be provided at the bottom of the shaft so that the hoisting leg can be drained to prevent plugging at the bottom of the pipe by the settled solids. Even though settling would not seem to be a problem because of the buoying force exerted by the water (and because other authors have indicated it not to be a problem in existing installations), protection should be included in the design.

In fact, emergency procedures for any underground installation and for all potentially dangerous situations should be developed by the designers in cooperation with safety experts.

Instrumentation

Instrumentation for mining or tunneling presents problems only in a few cases. The excellent current technology involving transistors, printed circuits, microprocessors, encapsulating materials, and wire insulation should prevent the old problems of failure due to moisture penetration, corrosion, and vibration. As with all underground equipment, great care must be taken to protect circuit boards and wiring from dust and from physical damage by vehicles and workmen.

One of the problem areas is in pressure sensors. Electronic sensors of the diaphragm type, while very accurate, are easily abraded or punctured by transported solids. Bourdon-tube-type gages are rugged but are susceptible to being plugged with fines. Means for protecting gages, without causing local pressure disturbances, must be developed. Proper location and installation are essential to performance. In pipeline research work it is well known that periodic maintenance is no guarantee that gages will operate reliably.

In coal mine hydraulic transport systems, concentration sensing for feed and flow control is a big problem, especially if there are wide variations in refuse content and concentration level. The usual means of concentration sensing is by gamma-ray gage. Because coal is a poor absorber of gamma rays, sensitivity is limited. The presence of rock in the coal distorts the absorption further. Such gages can work reasonably well for a steady flow of clean coal but are not reliable for raw coal and for research work. One Bureau of Mines project is to develop an

accurate concentration sensor that will measure both coal and refuse. It is probable that gamma-ray gages would work well for tunnel muck in pipelines.

Magnetic flowmeters have performed well in research work. A problem is encountered only when magnetic particles are involved, as with magnetite ore. The magnetic particles are attracted to the electrodes and coat them, reducing sensitivity. Once the problem is identified, this is easily compensated for by periodically switching polarity on the electrodes to clean them.

Economics

Another problem is that of obtaining an evaluation of capital and per-ton costs for comparison with those of conventional haulage systems. Because of the lack of technology and because of the current escalation of costs and variability of delivery times, generalizations about costs are misleading. A cost analysis must be done for a particular system configuration, using state-of-the-art technology and equipment.

In an effort to obtain some measure of the cost of hydraulic transport versus conventional mine haulage, in 1973 the Bureau of Mines awarded a contract to the Colorado School of Mines Research Institute to do a feasibility study (A24). The results of the study indicated that while the capital investment for hydraulic haulage is higher, the potential increase in production and productivity made the per-ton cost of hydraulic haulage significantly lower than for the conveyor belt haulage system with which it was compared. It also indicated the areas of the technology that were weak and needed work.

Coupled with the inherent safety advantages, the report has provided the incentive for an intensive research program by the Bureau. This

research effort is expected to provide the design data for systems, equipment, and operation that will significantly improve current estimates for costs, efficiency, and effectiveness of hydraulic transport for coal mine haulage.

Where Are We Going?

The history of hydraulic haulage installations has provided a base to build on. While the advantages of hydraulic transport for underground work have become more apparent, the cost of such untried systems has made interested organizations reluctant to venture into it. The reluctance is a sound judgment based on the lack of technology to permit a well-engineered design for the most efficient and reliable system possible. The answer is research, but few industrial organizations are willing to commit the time and money to do the job. Those who do keep such information for competitive advantage, as is only natural. More than half of the organizations in the list of experimental facilities in Tables 2 and 3 are Government, university, or related groups. Because of the number of nations involved, there have been difficulties in communicating and coordinating knowledge for advancing hydraulic transport technology. An organization has now been formed for the purpose of interchanging information among member nations on mining research areas with periodic reports of results. Among the member nations are the United Kingdom (National Coal Board), West Germany (Steinkohlenbergbauverein), and the United States (Bureau of Mines). All of these nations are pursuing underground hydraulic transport, and although the organization is new, efforts are being made to provide coordination at the working level and to report results.

Plans for future work are many, again as indicated on Tables 1, 2, and 3. A full-scale coal mine haulage system is planned for the Hansa mine in Germany, to be in operation in late 1977. This will be the largest capacity system built to date. It will have two underground sections with centrifugal pumps, and hoisting is to be done with a pipe feeder.

In England, the BHRA has just built a research pipeline facility, primarily for wear testing and pump development. Six-, eight-, and ten-inch pipelines are included.

In the United States, Conoco/Consol has completed development of a continuous haulage face system having a 1,000-foot extendable and retractable section. Surface testing has included research and testing at their Ponca City (Okla.) Research Laboratory and wear testing of pipe and hose at Consol's Loveridge mine. Plans have been announced for a large underground haulage system to be completed in 1978 at the Loveridge mine. Two continuous miner sections and a longwall section will be serviced. The raw coal will be pumped about 900 feet vertically and 2-1/2 miles overland to the preparation plant (A48,A55).

In Essen, West Germany, a pipeline test facility is being built which will have six pipes ranging from 4 to 14 inches in diameter. Solids up to 4 inches in size will be pumped. Tunnel muck as well as coal will be studied because of the experimenters' belief in the potential advantages of hydraulic transport for tunnel construction.

Also in West Germany, the University of Hannover is planning a large test facility with pipe diameters up to 20 inches. However, no more information is available at this time.

The Bureau of Mines has in progress a comprehensive program to develop engineering design data and equipment for underground coal mining. The first step was the previously mentioned feasibility study to establish the desirability of the program. Subsequently, contracts have been awarded, as follows:

1. To conceive, design, and develop a dry-feed coal injector to fit 4-foot or thinner coal seams. Two concepts, out of over a dozen candidates, were developed and tested in model scale (3-inch pipe) and show promise. Construction and testing of a full-scale prototype of one or both will follow. At this time, details cannot be provided on four of the candidate systems because of patent considerations.

Of the two units that have been tested, one has had a patent applied for. It is a screw-fed rotating-impeller device which accepts dry coal and operates at such speed as to prevent the outflow of water from the pipeline. The model has achieved the injection of 1 ton per minute of 1-inch coal against a pipeline pressure of 94 psi. The projected capability for a 10-inch pipeline size is 9 tons per minute of 3-inch coal against 94 psi.

The other unit tested is a jet pump. The jet operates submerged in a small pool of water to prevent air ingestion and has achieved an injection rate of 0.7 ton per minute of 1-inch coal. The discharge pressure was only 23 psi, which would require a downstream booster pump, but the compact size and simplicity of this injector make it attractive. The need for a booster pump is a disadvantage; however, it can be located at a reasonable distance from the face.

The other candidates for which patents are under consideration involve a rotating horizontal lobe, a sealed flight screw, and a novel

multiple-piston system. Other candidates involved peripheral jets or rotating jets flushing circular tanks, sliding vanes, floating pistons, peristaltic motions, and pipe feeders. Existing equipment was surveyed, and over 200 patents were examined in the process of developing candidate injectors.

2. To analyze the optional pipeline arrangements for a multiface, multisection coal mine and to determine the most economical and effective systems. The number, sizes, and routes for the pipes, location and sizes of surge storage, and the effect of variable-speed operation are being examined. This work is still in progress but will be completed this October.

3. To analyze a haulage system for automation potential by prescribing the equipment, operation performance, and cost for several degrees of automation. This work is still in progress but will be completed this November.

4. To conceive, design, and develop a sensor to measure the concentration of coal and of mine refuse in a pipeline. Thus far, a promising system has been conceived which combines gamma-ray, neutron beam, and conductivity sensors. A model to fit a 6-inch pipeline is being built for testing. If it is successful, sensors for larger pipelines will be tried.

5. To provide data for the engineering design of hydraulic haulage systems, the Bureau of Mines is constructing the Hydraulic Transport Research Facility (HTRF) at the Pittsburgh Mining and Safety Research Center in Bruceton, Pa. Figure 1 shows what the facility will look like when it is completed in early 1979.

The primary purpose of this facility is to generate design and operating data for the transport of run-of-mine coal in underground mines. Other uses will be to study the merging of transport streams, to develop operating methods, to test equipment and pipeline materials, to train operators, and to develop pipeline design data for other minerals. To avoid the problems and delays in working underground such as mine inspections, miner strikes, and difficult working conditions, it was decided to perform this work at a surface facility.

The HTRF was designed to eliminate the problems of degradation in the pump and pipeline and of large head-tank inventory by separately metering the coal and the water into a very small mixing tank. The coal will travel through the pipelines and at the end will be separated, the water going to a clarification system and the coal back to the storage bins. By having a large supply of coal and by returning it to the top of the bin, the system can use "fresh" coal until the returned material reaches the bin outlet, and then another cycle can begin.

Separation of the transport stream will be accomplished by vibrating screens and sieve bends. Dirty water will be cleaned to 300 mg/l by flocculation and separation in compact clarifiers with the underflow going to a vacuum filter system. Treatment of the water by a caustic system will be done as required.

The 12- and 18-inch pipelines are arranged to go out horizontally under the roadway for a distance of 180 feet, then downward at a 45-degree angle for 75 feet, then vertically upward 150 feet to a final 250-foot horizontal return to the building. The 6-inch pipeline will go

straight out 250 feet to a 90-foot vertical section and then return through a 250-foot horizontal section. The first sections will be used to determine wear and headloss in various pipe materials and linings by periodic measurements. The vertical sections and the horizontal return sections will be used for headloss measurements. In each vertical section, two pneumatically operated knife-gate valves can be actuated in the event of plugging to isolate the contents into three segments for easier dumping from the foot of the column into a reclaim sump.

Sampling will be accomplished by means of a valved "Y" at the discharge end of the pipelines. The samples will be collected in closed tank cars for a timed interval. Volume, weight, and solids particle size will be measured.

A data-logging system, coupled to appropriate instruments, will collect data and monitor the operation of the system. Pressure sensors which can be flushed of fine materials are located at about 80-foot intervals along each pipeline. Two magnetic flowmeters and three nuclear density gages are provided on each pipeline for data acquisition and control purposes. The raw data will be collected, formated, and printed out periodically on a 200 line per minute printer. Problem data will be annunciated on the operator's mimic panel, where he has access to the system by a keyboard. Certain responses to emergency conditions, such as plugging, will be actuated automatically, should the operator not provide manual control.

Design capabilities of the HTRF are given in Table 4.

How can this technology be applied to tunnel excavation?

An analysis of the application of hydraulic transport to tunneling needs was presented as part of a report on a contract let by the U.S. Department of Transportation in 1970 (A29). The report dealt primarily with large-scale operations anticipated for the future and concluded that hydraulic transport was among the lowest cost haulage systems for the driving of both tunnels and shafts. While data for analysis were very scant at that time, I believe that the report provides the basis for pursuing research and more detailed analysis in this area. I further believe that ultimately the findings will be verified in practice.

I have described the state of hydraulic transport technology in coal mining, which is closely related to tunnel excavation. Much of this technology is applicable for serious analysis of the systems and problems of excavation work. A coordinated effort by industry associations, universities, and the Department of Transportation can lead to the development and usage of hydraulic transport to drive tunnels, quickly, safely, and economically.

TABLE 1

Production Coal Mine Installations

Earliest Record	Nation	Coal Mine	Rated NTPH	Pipe diam, in	Maximum coal size, in	Surface, ft	Shaft, ft	Entry, ft
14	UK	(Power Plant)	50	8	5	1,750	0	0
8-57	Poland	Debiensko	110	10	3-1/4	0	1,015	16,400
58	Poland	Sierza	-	-	3/8	-	360	-
58	Poland	Andaluzja	130	-	2	-	995	-
6-59	USSR	Sutogan	45	-	-	-	1,310	-
6-59	USSR	Selidovugol 15	23	-	-	-	425	-
9-60	USSR	Selidovugol 105	35	-	-	-	-	-
9-60	USSR	Ordzhonikedzeugol 4	-	-	-	-	-	-
4-61	USSR	Krasnoluchugol 160	-	-	-	-	-	-
5-62	France	Devillaine	60	8	3-1/4	215	590	0
4-68	Japan	Sunagawa	140	8	1-1/4	4,450	1,690	590
6-70	Japan	Yoshima	110	6-1/2	2-1/4	-	830	-
70	USSR	Baydayevskaya-Severnaya -1	-	-	-	32,800	0	0
1-74	China	Lu-Cja-To	45	16	1/25	-	1,550	-
5-74	W. Germany	Karl Funke	80	5-1/2	1/25	18,000	2,500	-
5-74	W. Germany	Gneisenau	140	8	2-1/2	980	2,300	980
10-76	W. Germany	Hansa	230	9-1/2	4	-	2,800	6,900 10,500

TABLE 2

Experimental Coal Mine Installations

Earliest Record	Nation	Colliery	Rated NTPH	Pipe diam, in	Maximum coal size, in	Surface, ft	Shaft, ft	Entry, ft
10-56	UK	Woodend	80	8	3	100	250	50 1/
6-57	Poland	Komuna Paryska	40	7	1-5/8	1,400	160	-
3-58	USSR	Perwomaisk	66	10	4	9,900	395	3,940
3-58	USSR	Gnilushinskaya 1	66	10	4	0	425	0
5-59	UK	Markham	195	10	3	950	0	0
6-59	USSR	Pervomayskugol	110	10	-	10,200	395	-
10-59	Poland	Czeladz	-	-	3/8	-	-	-
9-61	USSR	Selidovugol 3	-	-	-	-	-	-
2-65	W. Germany	Dahlhausen Tiefbau	9	2-3/8	-	-	2,500	5,600
70	USSR	Don UGI	-	8	-	13,120	0	0
70	USSR	Ukr NIIGidrougol	-	12	-	4,264	0	0
5-74	USA	Robinson Run	300 2/	10	4	-	115	2,950 3/
5-74	USA	Humphrey	-	10	4	400, 700	0	0
78	USA	Loveridge	-	8	-	0	0	-
			-	14	-	0	0	-
			-	12	-	12,672	900	0

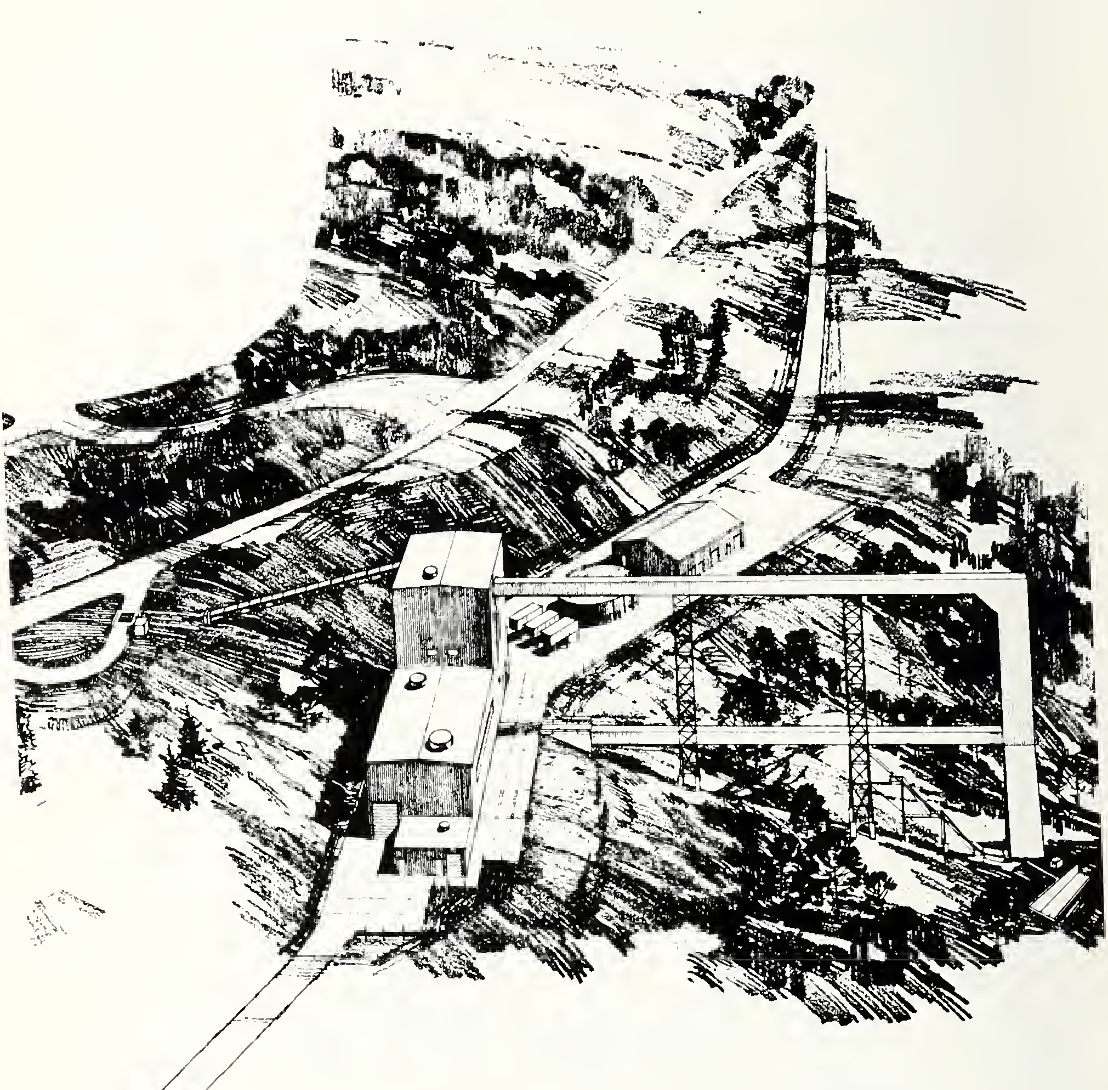
1/ 30 degree incline.
2/ 5.3 TPM
3/ Combined entry and surface.

TABLE 3

Experimental Surface Facilities

Earliest Record	Nation	Organization	Pipe diam, in	Maximum coal size, in	Horiz, ft	Vert, ft	Slope & Section Angle, deg	Length, ft
9-58	Neth.	DSM Lab.	6	3-1/4	0	60	0	0
3-63	Austral.	Unisearch, Ltd.	4	3	0	55	0	0
64	USA	USBM	6	2-1/2	0	65	0	0
8-69	USA	USBM	6	2	5,280	32	0	0
8-73	Canada	Sask Res Council	2	1/4	80	-	0	0
			4	1/2	200	-	0	0
			6	1/2	300-	-	20	0
			8,10,12	1/2	400	-	0	0
74	USA	USBM	1	1/4	70	5	0	0
			3	2	150	12	0	0
			6	2	650	35	0	0
5-74	UK	BHRA	1	fine	150	-	-	-
			3	fine	150	-	-	-
			6	4	140	0	15	-
			8	4	160	40	15	-
			10	4	330	0	15	-
5-74	USA	Conoco, OK	8	2-1/2	650	30	0	0
			10	2-1/2	200	30	0	0
76	W.Germany	Hannover Tech U.	20 max	-	-	-	-	-
76	USA	Williams Bros, OK	4	1	625	-	-	-
5-76	France	U. of Toulouse	2	-	160	-	-	-
			4	-	325	-	-	-
			8	4	650	-	-	-
5-76	Japan	Hitachi	4	-	500	-	-	-
6-76	W.Germany	Essen	4,6,8, 10,12,14	4	260	-	-	-
6-77	USA	CSMRI	6	2	400	65	0	0
			8	2	400	0	0	0
79	USA	USBM	6	2	500	65	0	0
			12	4	430	150	-45	80
			18	6	430	150	-45	80

FIGURE 1



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HYDRAULIC [illegible]
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TABLE 4

Coal Handling System	No.	Capability
Storage bin capacity	2	150 tons each
Weigh feeders	2	1,000 tph max. each
Crusher	1	50 tph @ 6-, 4-, 2-in top size
Vibrating screens	6	+1/4 in, 6 x 16 ft decks
Sieve bends	16	+35 mesh, 6 ft wide

Water Handling System		
Storage tank capacity	1	190,000 gal
Clear water pumps	2	20-in, 7,200 gpm
Clarifiers, compact type	3	2,000 gpm
Design particle size		50 mesh
Vacuum filter	1	4.35 tph
Design particle size		400 mesh
Cake moisture		50% by weight

Transport System

Pipelines	6-in	12-in	18-in
Pipe schedule	40	40	40
Length, feet, approx.	723	760	790
Bend radius, pipe diameters	10	7.5	5
Run time per cycle of coal at max. velocity, minutes	44	16	7
Velocity, fps, max.	15	18	18
Concentration, C_v, percent	45	45	45
Pumps (maximum capability)			
Discharge diameter, in	6	12	12
Number	2	1 or 2 1/	2 2/
Velocity, fps	15	18 2/	18
GPM	1,350	6,300	12,600
Total head	368	209	131
Motor Hp.	2 @ 200	1 or 2 @ 800	2 @ 800

1/ Higher velocities can be obtained by the use of the second 12-in pump.

2/ Initially, will use two 12-in pumps in parallel. Provision is made for future installation of an 18-in pump.

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PAPER 9

Pneumatic Pipeline Systems

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WORKSHOP ON MATERIALS HANDLING

FOR TUNNEL CONSTRUCTION

Keystone, Colorado   August 3, 4, 5, 1977

PNEUMATIC PIPELINE SYSTEMS

Presented by Lawrence G. Caldwell, Marketing Manager
Ducon Fluid Transport, King of Prussia, PA

The use of air as a medium for the removal and transport of material from tunnel construction would appear to have obvious advantages. Air can be drawn from the surrounding atmosphere and, after having provided the means of transport, can be returned to the atmosphere. Use of water or other dense media, on the otherhand, poses problems and/or dangers in the event of rupture or leakage of the supply system. Pneumatic handling, being a fluid method, permits the use of piping for a most flexible and simple pathway for transport. One could also conclude that the pneumatic method would require equipment with the very minimum of moving parts in the vicinity of the work.

It is an objective of this paper to question why there is so little being done in underground pneumatic handling of rock and to point up the technical problems being faced by those few

who are working in the field. As one goal of this workshop, a direction should be sought for research and development that would more rapidly bring the pneumatic technique into tunnel building technology.

A brief consideration of the theory of conveying particulate solids with air is necessary, I believe, if we are to appreciate the problems encountered in handling rock.

Air, compared to water, is a very low density fluid; and most important, air is compressible. In horizontal pipelines, maintaining the velocity of rock particles to insure that they do not settle out in the bottom of the pipe in such a low density medium, requires high air velocities, on the order of 6,000 to 7,000 ft. per min. as a minimum. The work to move the particles is being delivered to the particles by the relative velocity between air and solids. This velocity can only be maintained throughout the length of the pipeline by the maintenance of a ΔP across the ends of the pipeline. The magnitude of the ΔP across the ends of the pipeline is a function of the length of the pipeline, its cross sectional area, the velocity of the air, and the solids flow rate. Usually, the solids flow rate, the length of the pipeline, and the air velocity required, are dictated. The pipe size remains the only option. Selection of a small pipe results in high air friction, a high solids loading of the air stream, and a consequent high ΔP of the system. We now face the dis-

advantage of the compressibility of air. To provide the minimum velocity needed to prevent settling out at the beginning of the system, it is necessary that a relatively large volume of air be gathered in at the blower intake and compressed to the required system pressure level. In passing through the pipeline and delivering work to the solids particles, the air gives up pressure, thus increasing in volume and finally emerging at the discharge end of the system at its original volume before compression. In very round numbers this means that a system operating at a ΔP of 15 PSIG undergoes a doubling of air velocity throughout its length; a 30 PSIG system a tripling of velocity, etc. Since the stone to be handled is in sizes that create abrasive wear of the pipeline, this increase in velocity becomes the most important consideration in a system design. Selection of a relatively large pipe size lessens the velocity increase and, therefore, reduces the abrasive wear. Most work to date has involved system pressures of around 10 PSIG.

The relatively high velocities of pneumatic conveying, when handling rock, cause extreme abrasion of the conveying pipeline. The degree of wear is influenced by the stone size. A 3" size is, at the moment, a reasonable limit. Since a pneumatic system must have reasonably uniform feed material, it becomes necessary in mining and tunnel building to introduce a crusher before the pneumatic system feeder.

Above-ground experience in the pneumatic handling of limestone in steel mills has produced components and techniques which are applicable to underground problems. The rotary feeders are designed with wearing parts of extremely hard alloy and have provision for external adjustment for wear and combined with spun cast hard iron pipe and replaceable wearback hard iron elbows for the pipeline have made these systems very acceptable to the users.

The earliest underground pneumatic transport of rock was probably done in Britain where for some years crushed shale has been backfilled into mine voids by this method. Shale, being low in abrasion, did not create serious problems in the rotary pocket feeder or pipelines of such systems, and so there are a number of such systems in use in British and European coal mines.

More recently the firm which pioneered the shale backfilling systems joined with a Canadian pneumatic conveying supplier to produce a system for backfilling with abrasive, hard rock in a metal mining operation in British Columbia. Not surprisingly, the greatest problem proved to be the abrasive wear on the rotary feeder. Although in the beginning the severity of this problem threatened to doom the project, the sponsors perservered through a number of changes to the equipment and the feeder design which resulted is now being applied in areas of interest to this workshop.

In the drilling of a 9 ft. diameter tunnel in Edmonton, Alberta, Canada, a pneumatic system accepts the rock produced by the tunneling machine and transports it to the surface. Telescoping pipe sections and a technique for inserting lengths to follow the advance of the bore have proven successful. It was found necessary to use a crusher before the pneumatic system feeder to produce uniformity and limit size to 3" maximum. An unanticipated problem was blockage of the transport system by clays and soft shales which were periodically encountered, but these created problems for the tunneling machine as well.

In Halifax, Nova Scotia, Canada, a similar tunneling operation employs a pneumatic rock transport system which involves a 2,000 ft. horizontal movement and a 120 ft. lift to the surface.

The rotary feeder design which has evolved from the experiences with the earlier pneumatic system combines extreme hardness of the parts subject to abrasive wear (600 to 700 Brinell) and simple external adjustability for wear.

Probably the most demanding application of present day pneumatic system technology is in a South African gold mine where it is applied to backfilling. Here the rock being handled is extremely abrasive and the wear adjustment on the rotary feeder is made once each day.

The pneumatic technique is also being used in coal mining for the vertical hoisting of coal and shale. An outstanding example of a system in current operation is one in which 80 tons per hour is being vertically lifted 1,600 ft.

In vertical pneumatic transport where gravity and air velocity are countercurrent, the minimum air velocity is very much lower than for non-plugging horizontal transport. This results in greatly reduced wear in vertical pipelines.

In underground rock handling we have seen the application of pneumatic transport to three (3) operations:

Tunnelling - where the output of a tunnelling machine must be carried away and raised to the surface. Solids flow rate is relatively low and air velocity is minimized to reduce abrasive wear. A crusher is required ahead of the pneumatic system feeder to limit maximum rock size.

Hoisting - for straight vertical lift to the surface. Solids flow rate can be high, but air velocity can be held low for minimum abrasion of pipeline.

Backfilling - for replacement of rock into voids. Requires high discharge velocities of pneumatic transport system for long trajectory and maximum impact. Solids feed rate is high. Abrasion of pipeline is highest.

The air mover for pneumatic rock transport systems is a rotary

positive, non-lubricated blower, sometimes referred to as a "Roots type" blower. It is equipped with an inlet air filter, inlet and discharge silencers (if required), a pressure relief valve, and a check valve. If change of location of the blower is contemplated, the machine with all of its accessories may be mounted on a structural steel frame for portability.

At the terminal of the transport system a receiver hopper or bin must be provided and the transport pipeline must be expanded before entry to reduce the velocity of the stone particles. In addition, surfaces in the receiver subject to stone impingement must be lined with abrasion-resistant material. Dust control in the form of a pulse-jet bag filter or a scrubber must be provided.

The pneumatic conveying of rock requires more power than other methods, but the experience of other industries would indicate that its other advantages would probably offset this.

In summation, we would say that in the long term pneumatic pipeline systems for removal of rock from tunnel construction will become a common method with great advantages and economies. This will take place only as the problems of abrasive wear in system components are reduced to acceptable limits. In the short term, we believe that study and development in this area must be undertaken by more agencies and vendors.

PAPER 10

The Need for New Concepts and Developments in Hoisting Systems

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The Need for New Concepts and Developments in Hoisting Systems

by

Donald Hutchinson[1/]

The most critical transportation system of an underground mine is the hoist which provides access to the underground workings. This system defines the economic life of a mine due to hoist speed and capacity which dictates the rate at which underground workings are developed and the rate at which ore or coal is produced. The whole mining operation and particularly the lives of the miners who are transported into and out of the mine, depends on the proper design and safe condition of the hoist. Although the importance of the hoisting system to the welfare of the mine is generally recognized, hoist design and technology are based on concepts which have not changed appreciably over the last hundred years. This current mine hoisting technology may not be capable of supporting the ever increasing demands for energy and raw materials. Therefore, there is an imperative need for new concepts and developments in hoisting technology.

Georgius Agricola illustrated some of the earliest underground hoist concepts in his De Re Metallica. The following illustration (figure 1) by Agricola shows crude windlasses in which the miner sits on a stick attached to the hoist rope or sits on the slope and simply holds onto the hoist rope. The next illustration (figure 2) shows a little more

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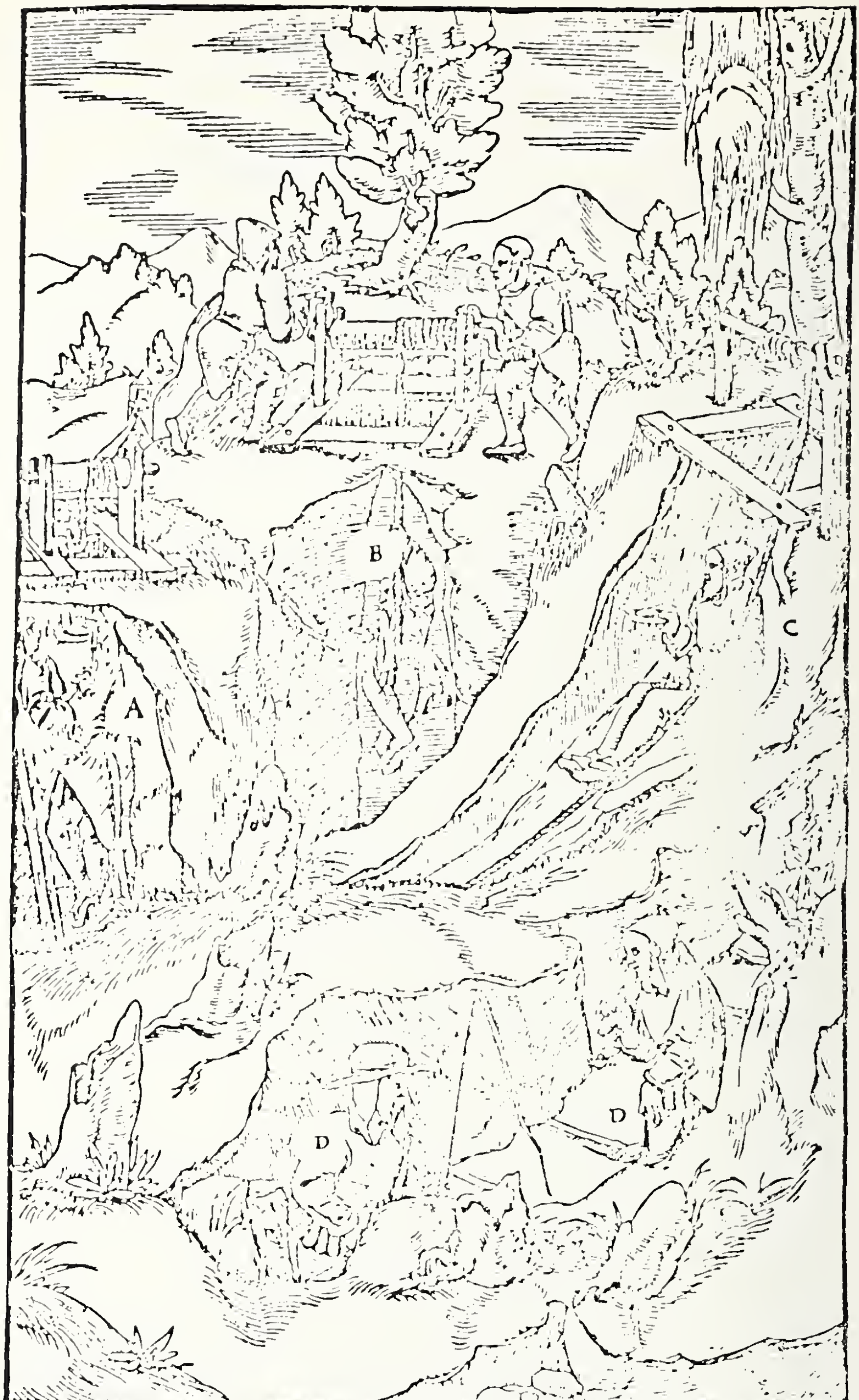
FIGURE 1

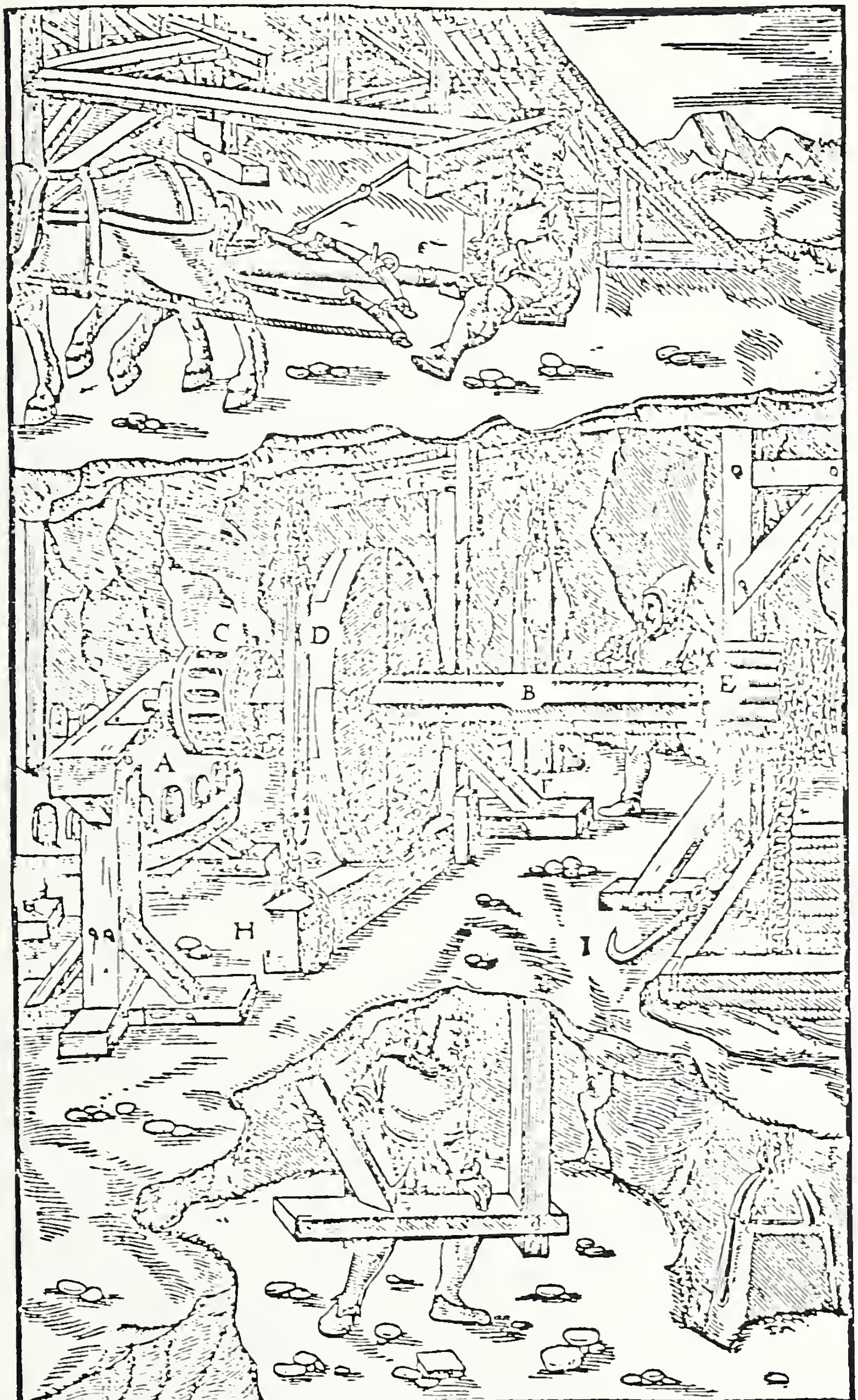


FROM: DE RE METALLICA BY GEORGIUS AGRICOLA

COURTESY AMERICAN BRATTICE CLOTH CORP.

A—Descending into the shaft by ladders. B—By sitting on a stick. C—By sitting on the dirt. D—Descending by steps cut in the rock.

FIGURE 2



FROM: DE RE METALLICA BY GEORGIUS AGRICOLA

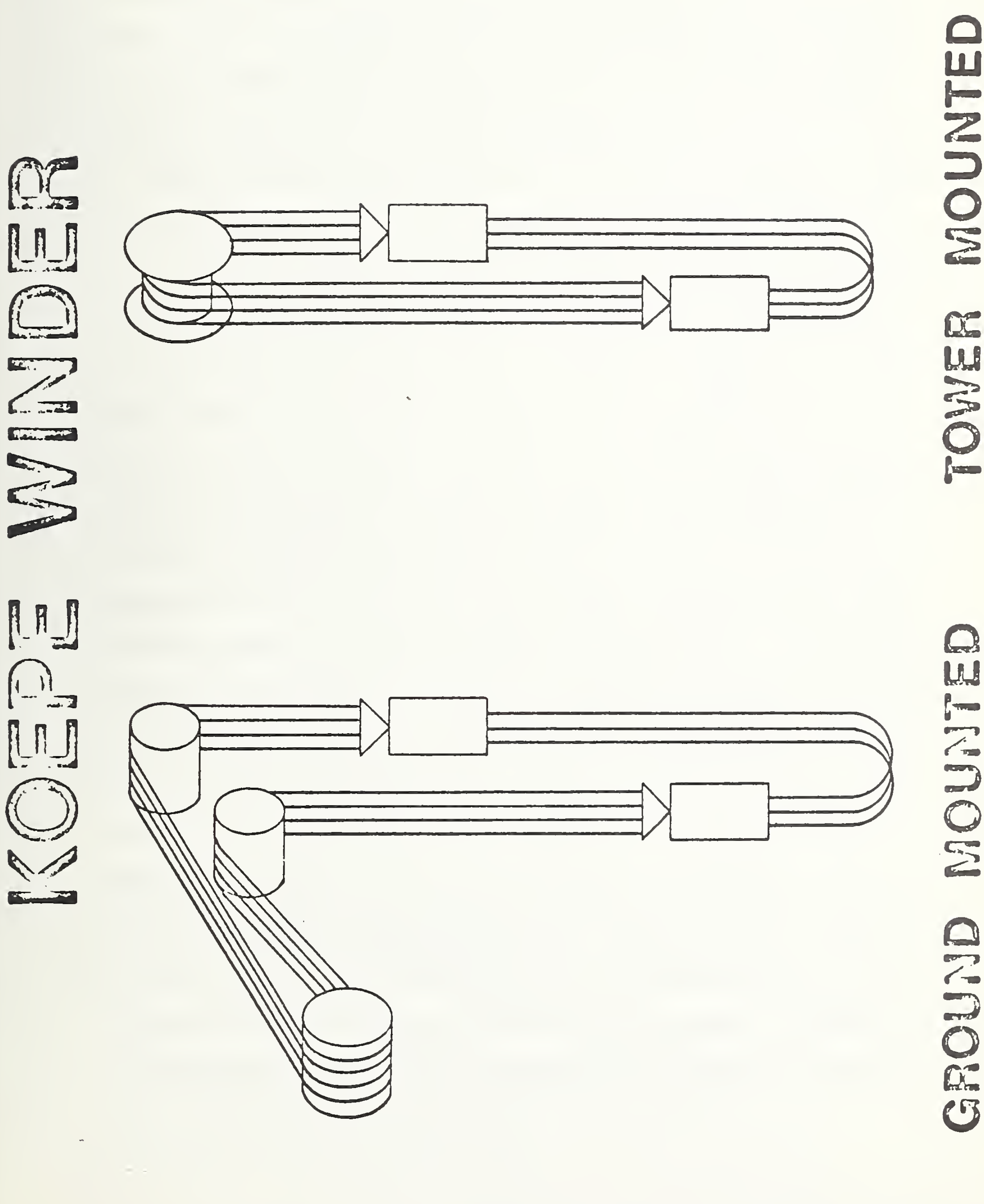
COURTESY AMERICAN BRATTICE CLOTH CORP.

A—Toothed drum which is on the upright axle. B—Horizontal axle. C—Drum which is made of rundles. D—Wheel near it. E—Drum made of hubs. F—Brake. G—Oscillating beam. H—Short beam. I—Hook.

sophisticated system. A horse whim or large capstan with radiating arms to which a draft animal is yoked provides the hoisting power. The capstan turns a crude gearing system consisting of toothed wheel and rundles which transfers torque from vertical to horizontal. The horizontal shaft drives the hoist drum which spools a chain. The brake is a version of a prony brake and shows the attention to devices to stop and hold a hoisted load as concepts became more sophisticated. Perhaps with the exception of hydraulic hoisting systems (material slurries transported in pipes), very few new ideas have contributed to the basic concepts of hoisting systems. The friction or Koepe hoist which has the hoist rope or ropes passing around a moving drum instead of winding around a drum is also an old concept. This concept shown in figure 3, has been used on almost all passenger elevators and dumbwaiter designs. The technological improvements in today's hoisting systems are in the mechanisms, power supplies, and control systems, but the basic concepts have not changed.

The basic need for new concepts and developments in hoisting systems may be questioned since existing systems seem adequate. Hoisting systems have been traditionally designed around economic considerations such as the depth, the relative value, and the estimated amount of ore or commodity. Therefore, the size of the skips, hoisting speed, and investment in the hoisting plant are vital economic considerations.

FIGURE 3



Currently, few coal mines in the United States utilize sophisticated material hoisting systems since coal is transported from the mine on a conveyor belt and hoisting is limited to providing transportation for the miners and mining supplies. This scheme has been successful since the coal beds mined have been easily accessable or the beds have not been so deep as to preclude sloping shafts that may be constructed at the proper grade (about 17° from the horizontal) to transport coal on a conveyor belt. However, recently in the United States, the demand for metallurgical coal has dictated mining beds as deep as two thousand feet. These mines employ sophisticated, fast, automated, hoisting systems for coal with separate hoisting facilities for men and materials. As strip mining and current mining of easily accessable steam plant coal depletes the resource, deeper mining and greater sophistication of hoisting systems will result. This economic principle has been evidenced in mining valuable metals where the metal may be less than one percent of the material mined, and the ore bodies are deep. The design of metal and nonmetal hoisting systems employs large skips, fast hoisting speeds, and sophisticated automatic controls.

Mr. D. B. McLaughlin of Dorr-Oliver-Long Ltd., described the evolution of skip sizes in a paper given at the Mechanical-Electrical Conference of the Canadian Institute of Mining and Metallurgy, January 25-27, 1977 in Sudbury. His analysis describes the Canadian mining industry, but it holds true for all of North America. Before 1950, the majority of

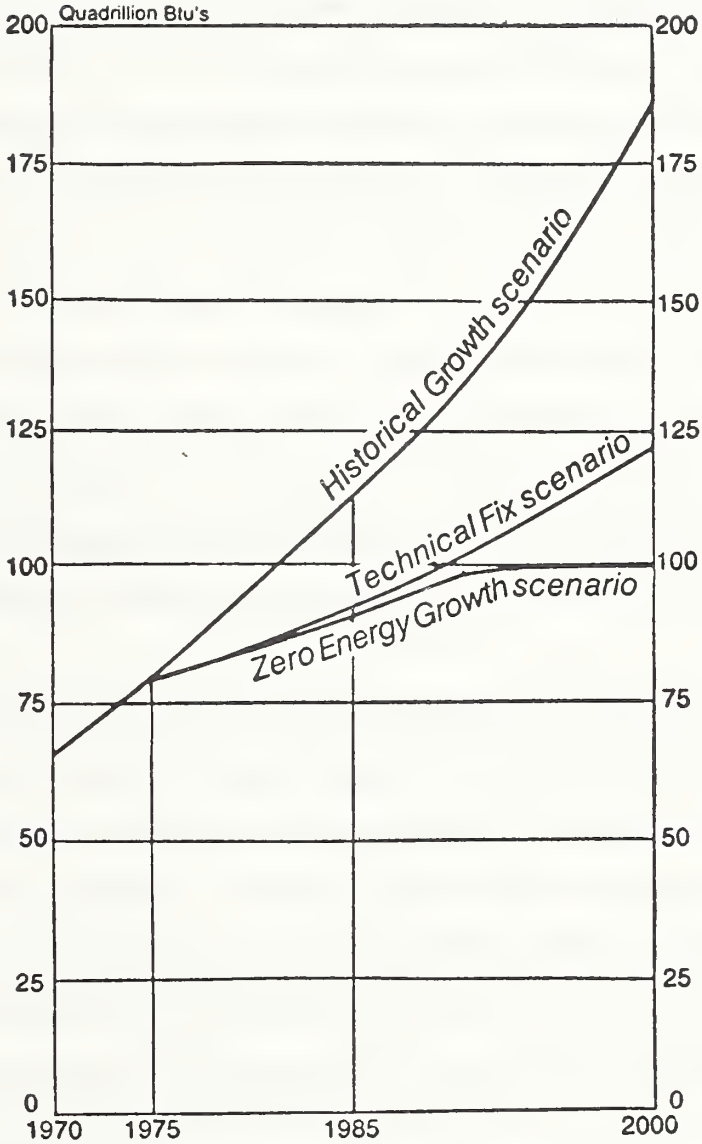
skip capacities were around 40 cubic feet to 60 cubic feet or 2 to 3 tons. During the fifties, skip capacities averaged from 100 cubic feet to 120 cubic feet or 5 to 6 tons and in the sixties skips with capacities of 180 cubic feet to 200 cubic feet or 9 to 10 tons were being installed as the large production copper and potash mines were developed. Today it is not uncommon to find mines going into production with 20 to 30 ton skips operating at speeds over 3000 feet per minute (1).[2/] Hoisting speeds have also steadily increased from a maximum of about 1500 feet per minute. These trends are shown in figure 4.

Currently there are fifty-four shafts under construction in the United States, thirty-seven were completed in 1976 and thirty-three in 1975 (2). It was recently predicted (Dahl, 1976) that the United States coal industry alone will require one hundred sixty new shafts each year for the next ten years (3). Include the shaft requirements for metal and nonmetal mines, and the estimate will easily go over two hundred shafts a year. All of these shafts will require hoisting equipment during construction and most will have permanent hoists installed. The exception is those shafts used for ventilation. The need for safe, efficient man hoists and high production commodity hoists will tax the capability of the mining equipment industry to supply them. Currently there is only one major hoisting system manufacturer in the United States.

2/ Underlined numbers in parentheses refer to items in the list of references at the end of this paper.

Due to the national attention to projected energy shortages and various schemes to cope with these shortages, there are numerous projections for coal mining, uranium mining, and oil shale mining. Several sources were consulted to anticipate future energy related mining in the United States. The first source is the 1974 Ford Foundation final report of their Energy Project Policy (4). In this report, three alternate futures, or scenarios, of possible energy futures through the year 2000 for the United States were considered. These scenarios were not offered as predictions, but were intended to be illustrative to help test and compare the consequences of different energy policy choices. The first of these three scenarios was the "Historical Growth Scenario" which assumed that energy use would continue to grow at about 3.4 percent annually and was based on no deliberate effort to alter our habitual patterns of energy use. The second scenario called the "Technical Fix" reflects a conscious national effort to use energy more efficiently through engineering technology. The result indicates an energy use growth rate of about 1.9 percent annually. Finally, a zero growth scenario was analyzed. This scenario includes all the energy saving technology of the Technical Fix Scenario plus extra emphasis on efficiency. The primary difference is a redirection of economic growth from energy intensive industries toward activities that require less energy. This redirection would be stimulated by an energy excise tax. The projected BTU use is shown in figure 4 for these alternatives.

FIGURE 4



Quadrillion Btu's
200
175
150
125
100
75
50
25
0
1970
1975
1985
2000
Historical Growth scenario
Technical Fix scenario
Zero Energy Growth scenario

Also in November 1974, the final Task Force Report on Coal for the Federal Energy Administration's Project Independence Blueprint was released. This task force was formed in April 1974 under direction of the U.S. Department of Interior to provide estimates for the Project Independence Blueprint of the potential production capabilities of the coal industry and the resources necessary to achieve these levels of production. This task force evaluated two alternative strategies. The first assumed that all the current policies that could affect levels of coal production would be continued and was called "The Business-as-Usual Scenario". The second alternative, called "The Accelerated Demand Scenario" assumed selected changes in policies or practices that would permit a greater expansion of potential production.

Many comments and criticisms have been leveled at these attempts to analyze future energy use. However, the overwhelming evidence is that coal production must increase dramatically during the next twenty years. It is also apparent that nuclear power will also share in providing needed energy. Unquestionably, coal and uranium will be mined in increasing quantities to a greater extent than ever before. A conservative estimate on underground coal production is 500 million tons by 1985.

The National Commission on Supplies and Shortages issued a final report to the President and Congress in December of 1976. The report concluded that "any significant materials shortage that the United States will

experience over the next 25 years (aside from energy) and probably for generations thereafter will not be due to resource exhaustion but to short-run shocks to the economy". The report further recommended that the Government develop means to control these shocks. One of the significant control mechanisms recommended was limited stockpiling of materials to protect the country against the impact of disruption in the flow of key imported raw materials and to deter threatened cartel actions by foreign materials producers. Proposed goals and current inventories are shown in figure 5 (4). President Carter announced on February 22, 1977, that a moratorium on defense related stockpile acquisitions and disposals was in effect pending a review of stockpile policy. The probable result of this policy will be an emphasis on production within this country. Therefore, to meet our national goals, future material hoist technology will continue to emphasize larger and larger skip sizes and faster and faster skip speeds. This trend is illustrated in figure 6. Without new technological concepts and resulting designs, hoisting speeds in excess of 5000 feet per minute cannot be anticipated. This is due to acceleration limitations and existing controller designs. Maximum controller speed currently available is 4800 feet per minute with a Lilly Model C 16 controller. Problems have also been encountered with high air velocity effects both from ventilation air in the shaft(s) and from dynamic lift. Skip sizes are also limited by shaft compartment and dumping facility dimensions. A thirty ton skip may be close to forty feet long depending on its other dimensions.

FIGURE 5

of Metals and Materials as of December 31, 1976

A. Materials With Current Stockpile Goals	*Unit*	*Goal*	*Inventory*	*Excess*	*Sold during 1976*
Alumina	s.tons	11.532.000	0	0	—
Aluminium Oxide Grain	s.tons	75.000	50.905	0	—
Aluminium Oxide Crude	s.tons	147.615	249.009	77.299*	16.973
Antimony	s.tons	20.130	40.714	20.584	—
Asbestos, Amosite	s.tons	26.291	42.623	16.332	192
Bauxite, Jamaica	l.tons (dry)	523.000	8.858.881	0*	—
Bauxite, Refractory	l.tons (dry)	2.083.000	173.000	0	—
Beryllium Copper	lb	33.420.000	14.773.731	0	—
Beryllium Metal	s.tons	895	229	0	—
Bismuth	lb	771.000	2.100.061	1.329.061	—
Cadmium	lb	24.701.000	6.328.955	0	125.000
Chromite, Chemical	s.tons (dry)	734.000	250.000	0	—
Chromite, Metallurgical	s.tons (dry)	2.550.000	2.504.560	0	—
Chromite, Refractory	s.tons (dry)	642.000	399.960	0	—
Chromium Ferro HC	s.tons	236.000	402.694	0*	—
Chromium, Ferro LC	s.tons	124.000	318.894	122.894*	—
Chromium, Ferro Silicon	s.tons	69.000	58.355	0	—
Chromium, Metal	s.tons	10.000	3.763	0	—
Cobalt	lb	85.415.000	40.724.533	0	5.172.859
Columbium Concentrates	lb	3.131.000	1.780.301	0	68.908
Copper	s.tons	1.299.000	20.261	0	500
Diamond Industrial, Bort	carats	14.974.000	31.033.723	16.059.723	2.542.923
Diamond Industrial Stones	carats	5.559.000	20.000.000	14.441.000	—
Fluorspar, Acid Grade	s.tons (dry)	1.594.000	889.991	0	—
Fluorspar, Metallurgical	s.tons (dry)	1.914.000	411.788	0	—
Graphite, Ceylon	s.tons	6.271	5.499	0	—
Graphite, Malagasy	s.tons	20.472	17.939	0	—
Graphite, Other	s.tons	34.748	2.800	0	—
Iodine	lb	3.333.000	8.011.814	4.678.814	—
Jewel Bearings	pieces	224.623.000	62.459.171	0	—
Lead	s.tons	865.000	601.160	0	459
Manganese, Battery, Natural	s.tons (dry)	12.736	264.533	235.700*	123
Manganese, Battery, Synthetic	s.tons (dry)	19.105	3.008	0	545
Manganese, Chemical	s.tons (dry)	247.136	220.996	0	7.000
Manganese, Metallurgical	s.tons (dry)	2.052.000	3.685.085	1.388.085*	42.660
Manganese, Ferro HC	s.tons	439.000	600.000	161.000	—
Manganese, Ferro MC	s.tons	99.000	28.921	0	—
Manganese, Silicon	s.tons	81.000	23.574	0	—
Manganese, Metal	s.tons	15.000	14.166	0	—
Mercury	flasks	54.004	200.062	146.058	—
Mica, Muscovite Block	lb	6.188.000	5.108.133	0	—
Mica, Muscovite Film	lb	90.000	1.330.606	1.240.606	19.814
Mica, Muscovite Splittings	lb	12.631.000	22.542.341	9.911.341	1.186.078
Mica, Phlogopite Block	lb	206.064	127.773	0	19.112
Mica, Phlogopite, Splittings	lb	932.000	3.047.953	2.115.953	357.975
Nickel	s.tons	204.335	0	0	—
Iridium	tr.oz	97.761	17.002	0	—
Palladium	tr.oz	2.450.000	1.254.994	0	—
Platinum	tr.oz	1.314.000	452.645	0	—
Rutile	s.tons (dry)	173.928	39.186	0	—
Silicon Carbide Crude	s.tons	306.628	80.619	0	—
Talc, Steatite, Block & Lump	s.tons	104	1.119	1.015	30
Tantalum, Carbide	lb	889.000	28.688	0	—
Tantalum, Metal	lb	1.650.000	201.133	0	—
Tantalum Minerals	lb	5.452.000	2.545.410	0	—
Thorium Nitrate	lb	1.800.000	7.265.004	5.465.004	17.800
Tin	l.tons	32.499	203.287	170.788	3.586
Titanium Sponge	s.tons	131.503	32.329	0	—
Tungsten, Carbide	lb	12.845.000	2.032.834	0	—
Tungsten, Ferro	lb	17.769.000	2.025.463	0	—
Tungsten, Metal	lb	3.290.000	1.765.366	0	—
Tungsten, Ores & Concentrates	lb	8.823.000	106.767.708	66.026.708*	3.708.407
Vanadium, Ferro	s.tons	10.095	0	0	—
Vanadium, Pentoxide (V cont.)	s.tons	2.576	540	0	—
Zinc	s.tons	1.313.000	374.830	0	—
B. Materials with Former Objectives But No Current Goals					
Aluminium	s.tons	0	5.426	0*	9.765
Asbestos, Chrysotile	s.tons	0	10.955	10.955	—
Bauxite, Surinam	l.tons (dry)	0	5.300.000	0*	—
Beryl Ore	s.tons	0	17.986	0*	—
Columbium, Ferro	lb	0	930.911	0*	—
Columbium, Metal	lb	0	44.851	0*	—
Diamond Dies, Small	pieces	0	25.473	25.473	—
Molybdenum Disulfide	lb	0	0	0	130.151
Quartz Crystals	lb	0	2.692.536	2.692.536	234.392
Sapphire and Ruby	carats	0	16.305.502	16.305.502	—
Silver (fine)	tr.oz	0	139.500.000	139.500.000	—
C. Other Inventories					
Asbestos, Crocidolite	s.tons	—	2.506	2.506	4
Celstite	s.tons (dry)	—	14.408	14.408	0
Diamond Tools	pieces	—	53.182	53.182	10.996
Kyanite Mullite	s.tons (dry)	—	2.816	2.816	0
Lithium Hydroxide	lb	—	3.110.235	3.110.235	1.983.869
Magnesium	s.tons	—	1.121	1.121	500
Mercury	flasks	—	756	756	1.020
Rare Earths	s.tons (dry)	—	7.174	7.174	55
Selenium	lb	—	0	0	2.500
Talc Steatite ground	s.tons	—	2.916	2.916	0
Yttrium Oxide	lb	—	237	237	0

*Part or all of apparent excess held to offset shortfall of other grade or form of same commodity.

Source: Adapted from Federal Preparedness Agency Reports

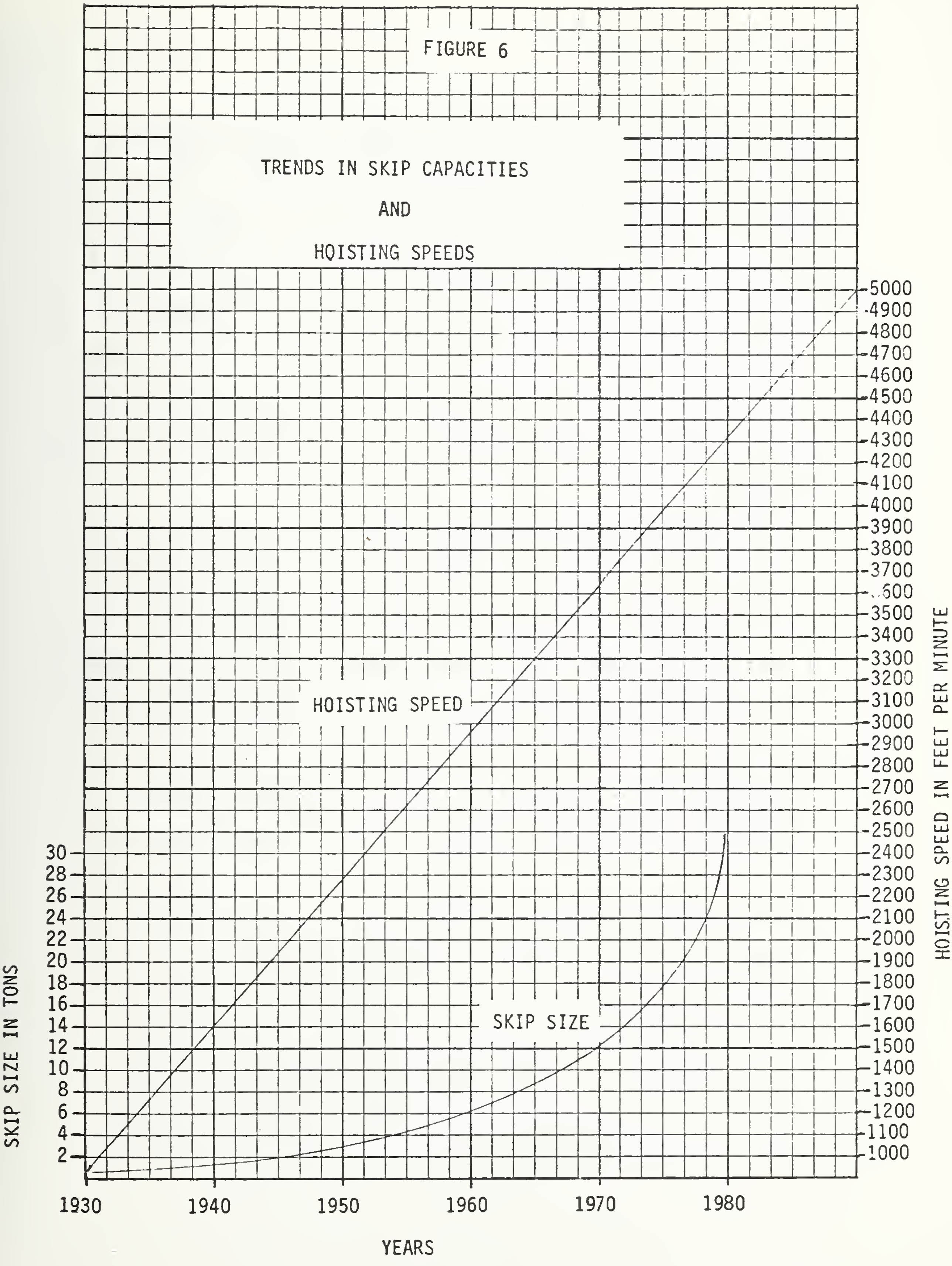


FIGURE 6
TRENDS IN SKIP CAPACITIES
AND
HOISTING SPEEDS
HOISTING SPEED
SKIP SIZE
SKIP SIZE IN TONS
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
HOISTING SPEED IN FEET PER MINUTE
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000
3100
3200
3300
3400
3500
3600
3700
3800
3900
4000
4100
4200
4300
4400
4500
4600
4700
4800
4900
5000
1930
1940
1950
1960
1970
1980
YEARS

Sweden, South Africa, and Canada have probably developed traditional hoisting systems to the highest degree of sophistication. South Africa and Canada are both employing light alloy skips with rubber liners and employing more front dump skips in their systems. Front dump skips have the advantage of less travel in the headframe and no need for dump plates and scrolls. In South Africa it has been recognized that the point of diminishing returns in hoisting capacity using traditional hoisting systems has been reached (7). Their conclusions are summarized as follows:

> Shafts and headframes although acceptable at present will be changed and improved as technology advances. Automatic skip loading systems are proving satisfactory but better control of spillage and remote monitoring systems are required before loading can be carried out without the service of a loading attendant.
>
> Operation of hoisting ropes is acceptable but improvement in strength to weight ratio and rope life must be actively pursued.
>
> The hoist then remains the weakest link in the operating chain and the following observations should be considered:
>
> In the quest for improved efficiency, control and safety, the electrical circuitry and braking systems of hoists have become extremely complex. This complexity, when applied to Ward-Leonard

systems employing relay logic for control and safety, requires that increasingly more time be allocated to preventative maintenance of converting and switching equipment and the amount of time required for maintenance has reached the limit of acceptability.

The introduction of static converters and solid state logic for control has been accepted as the necessary breakthrough for further control improvements. Little preventative maintenance is required and it can be reasonably expected that system reliability will be improved.

The level of technical competence for trouble-shooting and maintenance of static control and logic systems are very high. It requires the services of personnel with particular aptitudes and special training and continuous learning is required in order to keep abreast in this field where the rate of change is very high.

Assessment of the reliability of a hoisting system continues to be difficult. In an effort to assure maximum reliability, the approach should be:

(a) Strive for mechanical simplicity, eg, direct coupled hoist motors, braking systems with minimum inertia, high pressure actuators to reduce hysteresis, and simplicity of control.

(b) Favor static converters, static control systems together with increased use of plug-in modules and integrated circuitry.

(c) Advocate the use of more fault annunciation as an aid to trouble-shooting.

(d) Specify more proven components and proven interface devices (7).

At some point in time we will reach a point of diminishing return using traditional hoisting systems and the economy of the mining industry, the energy future, and commodity independence of this country will depend on new hoisting concepts and technology.

Currently the Federal Government is funding research projects through the Bureau of Mines on skip and guide technology, hoist rope retirement criteria, hoist rope terminations, and techniques to train hoist operators. However, additional funding should be invested in new concepts and technology to safely and rapidly transport large amounts of material from deep within the earth. At the same time, technology

is also required to improve man hoisting systems and this should also include escape hoists. As mines become deeper, the logistics of evacuating miners in an emergency under hostile ambient conditions becomes a primary consideration. Escape systems must have high reliability and low maintenance to be effective.

Probably the most difficult hoisting problems encountered in mining are during shaft sinking. Current practice is to use the same hoisting system both for raising broken rock to the surface and transporting men, materials, and machinery in the shaft. The resulting logistic problem contributes to the high cost of sinking and probably to the current high accident rate during shaft sinking. As deeper shafts are constructed, the problems become more severe and methods used for shallow shafts are marginal beyond certain depths. Studies have also been contracted by the Bureau of Mines to investigate the safety problems of shaft sinking.

In conclusion, the need for new concepts in both material hoisting and man hoisting is immediate and critical to provide for the mining requirements of the future.

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PAPER 11

Bucket Elevators

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DEPARTMENT OF TRANSPORTATION
WORKSHOP ON MATERIALS HANDLING
FOR TUNNEL CONSTRUCTION

KEYSTONE, COLORADO
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BUCKET ELEVATORS

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The bucket elevator is probably the oldest known type of conveyor. The earliest known form of bucket elevator dates back to biblical times, and encyclopedias and history books are replete with drawings of wicker baskets affixed to ropes, operating over wooden pulleys. These devices were used to lift river water into irrigation ditches.

This crude elevator has gone through centuries of development, improvement, and technological advances. Today, there are thousands of installations all over the world in which hundreds of different types of bulk materials are being elevated continuously, successfully and economically.

While the proper selection and application of this type of equipment has reached a high degree of technology, it remains substantially an art. Such reference to elevating materials as both a science and an art is made advisedly because the solution of most material handling problems is not susceptible to a single definite answer but depends largely on the experience and judgment of individual material handling engineers.

A formal definition of a bucket elevator could read as follows:

"A conveyor for carrying materials in a vertical path consisting of endless belt chain or chains to which elevator buckets are attached, the necessary terminal machinery and supporting frame or casing."

The belt or chain operates unidirectionally, so the definition eliminates skip hoist and freight elevators from the discussion.

It would be well here to make a very strong point that all elevators are volumetric units; that is, for a given speed and set of components, the capacity in cubic feet per hour remains constant. Tonnage, therefore, varies as the density of the material being handled.

Vertical Elevators

Vertical bucket elevators can be generally classified into four types. These types are named for the way they convey and discharge material.

Centrifugal Discharge Elevators

Material is discharged by centrifugal action. These units consist of buckets mounted on chain or belt and operate at speeds of 250 FPM to 400 FPM minimum. Lump size of handled material is usually no more than 2 inches. Common industrial units are available in capacities from 300 to 3,500 CFH with heights seldom exceeding 80 ft. With the advent of the cement mill elevator in the early 1950's, specially designed chain and buckets operating at higher speeds extended the centrifugal discharge elevator to capacities in excess of 25,000 CFH and heights of 150 to 200 feet.

Since this type of unit is a "digging" elevator and confined to handling large volumes of very fine material, it is not applicable to tunneling service, so little more than a mention will be made of it here.

Positive Discharge Elevators

A spaced bucket elevator in which the buckets are turned over by use of idler wheels. Buckets are maintained over the discharge chute long enough to permit free gravity discharge of bulk materials. These units operate at speeds of no more than 120 FPM and are used to handle sticky materials or materials which tend to pack. Positive discharge elevators are also "digging" types with small capacities; however, one of its features will be touched on later.

Continuous Discharge Elevators

Material is discharged by gravity. Buckets are mounted on a continuous chain and operate at speeds of 100 to 150 FPM. Continuous discharge elevators will successfully handle materials of 2 to 5 inches. A specialized type of continuous elevator called Super-Capacity has very large buckets mounted between two strands of chain. It is best suited to handle large lump materials. Operating speeds are generally in the range of 125 to 150 FPM and easily handle 8" lumps. It is this type of elevator which is best suited to muck handling operations in tunneling projects and on which we will concentrate in this discussion.

Materials Handled

Before a particular type of elevator can be selected, or for that matter, proper components for a particular type, a complete analysis of the material to be handled must be made. Material size, degradability, hardness, moisture content, contamination--all must be considered.

Manufacturers of elevators have package equipment with a given rated capacity, speed, bucket, and all other appertenances, so that the proper elevator can be selected for average bulk materials.

An average bulk material is here defined as one which has the following characteristics:

1. Lump size of under 8 inches with a high percentage of fines.

2 No unusual flow problems that require special buckets.

3 Materials that have temperature ambient or slightly elevated.

4 Materials which are neither extremely abrasive (plus 7 Moh) nor extremely corrosive.

5 Usually not degradable in normal handling.

It should be immediately obvious that mucking operations in tunnel work violate more than one of these parameters. We are thus dealing with a non-average material. Non-average materials include materials which contain free water and primary crushed rock with lump sizes primarily in the 6 to 8" size or greater.

These non-average materials may be handled in a vertical bucket elevator, but require special considerations such as materials of construction peed, and bucket design. Another material characteristic which ay require special features in an elevator is sluggishness. Such materials may require special features, such as bucket holes or special shapes to provide good discharge.

Having covered most of the academics of material handling in bucket elevators, our discussion will now concentrate on the Hi-Load or Super-Capacity bucket elevator, as applied to tunneling projects.

The general configuration of a Hi-Load or Super-Capacity elevator of commercial design is illustrated here. Since the term Hi-Load is our own tradename and Super-Capacity is more or less a generic term, reference will hereafter be made to the latter.

Components consist of style HL buckets varying in width from 16 to 48 inches, mounted between two strands of chain operating over hardened steel head sprockets and either sprockets or traction wheels in the boot. The unit incorporates an internal gravity takeup which provides constant slack side tension, automatically compensating for elongation or stretch in the tension medium. The all steel casing is continuously welded for dust tightness and is self-supporting; that is, it is engineered to transmit the entire load on the headshaft to the base or boot of the elevator. It is important to note that "self-supporting" does not mean "free standing". The casing must be laterally supported at approximately 20 foot intervals to maintain plumbness for proper operation.

These elevators range in capacity capability from 6,500 CFH to 20,000 CFH at a speed of 135 FPM. Handling rock at 100 PCF density, this equates to tonnages ranging from 325 TPH to 1,000 TPH. Height ranges in industrial service range from 75 to 150 ft. and capital costs approximate 50,000 to 75,000 dollars per unit.

While all components and structurals which make up the Super-Capacity elevator must be matched in serviceability to meet the demands of a particular application, the carrying medium consisting of buckets and tension members requires particular consideration.

The chains or tension members must have the strength and fatigue reliability to provide the optimum hours of service required to realize full production, maximum anticipated thru-put, and minimum downtime for maintenance. Also, the various parts which make up the chain, particularly the articulating joints, must be hard enough to resist abrasive wear from the material being handled.

When the mineral hardness of the material handled exceeds chain joint hardness, poor chain life results. But, when the chain joint hardness exceeds mineral hardness, long chain life is possible.

The technology of chain manufacture has progressed through the stages of early all cast chains to combination steel sidebar and cast block link types, cast manganese chains, and, finally, today's finest all steel precision built chains, all in the interest of higher working loads and corresponding increased center distances.

Modern all steel chains with induction hardened pins, deep case hardened bushing, and heat-treated alloy steel sidebars are commercially available with minimum ultimate strengths of well over 200,000 lbs. In service which demands 24 hour a day operation and minimum of 40,000 hours of life, the allowable working loads on these chains are derated to about 20,000 lbs. in order to extend fatigue life.

When we consider the heights of these elevators required in tunneling projects where chains may be subjected to 30,000, 40,000, or more pounds of tension capability, the initial tendency would naturally be to build bigger chains, larger pins, bulkier sidebars, etc. This is not the answer. Adding bulk to the chain itself defeats its own purpose, and we reach the law of diminishing returns, whereby, the chain has to be so strong to support its own weight that little is gained in additional height capability.

A more sophisticated approach must be taken--better materials, construction techniques which result in a chain to realize the maximum potential for its physical size.

A chain has already been developed and a prototype built and tested to where it is now known that within the dimensional limitations of existing industrial chains, a working load of 50,000 lbs. per strand can be applied. What does this mean from a height standpoint? It means an increase of 30 to 40 percent over units now marketed can be built. It should be noted that at this moment in time, the commercial production of this chain has been resisted. Naturally, its capital cost is higher and the market for such a chain has not yet been defined.

Typically, Rexnord designs its chains to wear out--not to break. Since accurate fatigue curves have been developed for all of our heavy precision steel chains, the number of cycles which such a chain can see without failing can be accurately predicted.

In tunneling projects, chains are applied above normal industrial working loads to meet the criteria of wearing out--not breaking. Essentially, all tunnel elevators fall in the category of limited life applications. The elevator only has to function at its maximum design thru-put for the anticipated duration of the contract. Starting with parameters as specified by the contractor, then using laboratory experience and to some extent field experience, the chain and maximum elevator height are selected on the basis of actual hours to complete a given project. Chains applied as is done here would conceivably fail before wearing out if continuously applied too far beyond predicted hours of operation.

In sizing for capacity, our attention turns to the buckets, themselves. Current requirements for handling mole output would not conceivably tax bucket elevator capabilities. Buckets are actually sized more for the maximum rock size to be handled than the tons per hour to be handled, even with the mole operating near maximum efficiency. From a capacity standpoint, the elevator could actually be loafing.

An old but still acceptably valid rule of thumb for bucket sizing states that "the maximum lump to be handled should not exceed approximately 2/3 of the bucket projection." The bucket length comes into play also, since more than one maximum size lump may be introduced to the elevator at a given moment. A minimum length of three times maximum lump would be considered an acceptable parameter. These general rules of thumb assume that the largest lumps make up 10% or more of the total load fed to the elevator. Again, the "art" of elevator application can prevail, if it is certain that large lumps will not comprise more than 1 to 2 percent of total load and the length of bucket can be reduced to a more reasonable size, in relation to actual capacity requirement. Also, with only occasional oversize material being anticipated, the size of the maximum lump for a bucket with

a given projection can be exceeded to an extent as long as it will physically fit within the confines of the carrying medium. Such judgment should be left to the expertise of the experienced material handling expert.

The advantages of the use of a bucket elevator in removing muck from a tunneling operation are obvious:

1. The material can be continuously handled, usually at a rate exceeding other methods exclusive of the belt conveyor.

2. The bucket elevator in a shaft brings the muck to the surface in the shortest distance between the invert and the surface.

3. These machines are compact in cross section and take up a minimum amount of room in the shaft, allowing for other lifting and lowering functions to continue, while conveying the muck to the surface.

4. The horsepower per ton of material handled will be lower or compare favorably with other means of haulage.

5. Additional excavation for its installation is minimal.

6. Capital costs of an elevator and its backup system will usually be lower than other lifting methods alone within the parameters of its height capability.

7. The structurals, drive, and terminals will conceivably outlast the tension members, so a given elevator could be rechained and either lengthened or shortened (within limits) for use on another project.

A first-class supplier of a bucket elevator system will usually have the capability of furnishing the elevator itself, the backup system consisting of dump hopper, grizzly, apron feeder and chutework, and the truck loading bin--essentially, everything from the car dump to the haulage trucks. The configuration of the backup system will differ depending upon whether side dump or rotary dump methods are used for unloading the muck cars.

Two installations are in operation at the present time, one in service for a section of the Metro system in Washington, D. C., and the second working in a portion of the rainwater storage tunnel complex in Mount Prospect, Illinois.

In anticipation that the material to be handled by the elevating machines would fall into the non-average material category, the standard 40 degree front bucket was changed to a 50 degree front version. The significance of the slope of the front of these

buckets is not immediately apparent until we examine the bucket attitude at the discharge position. Since Super-Capacity elevators discharge by gravity, the backside of the front plate of the bucket acts as a continuation of the discharge spout when inverted at the headend. Thus, the load from the bucket in back of or the succeeding container of the one presented at the discharge chute cascades over this temporary chute and is directed into the discharge opening. An adjustable peeler lip is a simple device added to prevent excessive backlegging by catching any late discharge and directing it out of the elevator with the main flow of discharged material. Besides incorporating chutework with minimum valley angles of 50 degrees or more, these were the only concessions to other than standard available industrial elevator units of this type.

The Washington installation has been in operation intermittently for about 1-1/2 years; however, because of initial problems involving other than the muck removal system, the elevator has, to date, seen only approximately 2,000 hours of full operation.

Data on the original muck removal equipment and design parameters follow:

Muck Cars =	12.6 cu.yd. - Side dump
System Design Capacity =	300 TPH
System Capability =	400 TPH

Equipment:

1 - 350 cu.ft. receiving hopper with inclined bar grizzly with 7" clear openings

1 - 36" wide apron feeder, 15'0" long

1 - 30" wide belt conveyor, 75'0" long

1 - REX 4124-03 bucket elevator, 175'0" centers

1 - Item associated chutework

Initial capital cost not including installation = $200,000.00

The Chicago installation has been in operation only about two months. At last report (July 22), the mole had progressed 2,600 ft. and number of operating hours on the muck system is less than 1,000.

Data on the original muck removal equipment and design parameters follow:

Muck Cars =	16 cu.yd.
	Rotary dump by Ray Moran
System Design Capacity =	250 TPH
System Capability =	350 TPH

Equipment:

1 - Receiving hopper with two-car capacity

1 - 36" wide apron feeder with 25'0" centers

1 - Symons vibrating bar grizzly to scalp off 7" lumps

1 - REX 4120-03 bucket elevator, 230'0" centers

1 - 135 cu.yd. truck loading hopper

1 - REX vibrating feeder

1 - Item associated chutework

Initial capital cost not including installation = $270,000.00

These installations have produced with varying degrees of success. It would be remiss to state that the muck handling arrangements have not exhibited certain problems. Being the first of their kind, a definite degree of learning process has been involved.

Most important in future designs is to recognize that material from a mole in tunneling projects cannot be assumed as consistently free-flowing material with constant moisture content. As the mole progresses, the consistency of the muck produced can change from day to day. Excessive free moisture and sluggish handling characteristics can build-up on all surfaces of normal material handling equipment and can become so serious as to plug up improperly designed chutework.

In the Washington installation, the inadvertent introduction of oversize rocks to the elevator bent and destroyed buckets, bulged the casing, permitted excessive backlegging and wore out the chain guides. When an elevator is sized for a particular size lump, every effort must be extended to limit the maximum size rock within these parameters, if successful operation is to be expected and unnecessary downtime avoided.

In both Washington and Chicago, chutes which were designed to change direction of what was assumed to be free-flowing material plugged up because of inherent inability of material to flow on itself or sluggish handling characteristics.

Rexnord has been responsive in working with the contractor in redesigning transfers and supplying alternate equipment to solve

these problems. Both arrangements are now operating and removing muck at better than design rates; however, in bad ground, the material handling equipment does require higher than normal maintenance.

It is now apparent that standard Super-Capacity units must be modified for full success in tunneling applications. On the basis of experience gleaned from these installations, it is entirely conceivable that a very workable and acceptable unit can be developed. Some desirable features can be resolved with present technology and developed in-house without extensive research. Others will require more research in-depth and lengthier programs for successful solution. It is now apparent that a truly reliable and successful bucket elevator muck handling arrangement <u>must</u> take into account such features as:

1. A bucket conformation which will permit free release of the most sluggish materials anticipated. Deep pockets and sharp bends or corner angles cannot be tolerated because of buildup problems.

2. Muck as produced by moles in tunneling cannot be expected to reverse direction in chutework. The angularity of some rock as it fractures from the tunnel face causes mechanical interlocking, making stonebox type chutes ineffective. The material will not move on itself and develops very high angles of repose. For right angle or other directions of transfer, physically moving the material with an intermediate transfer conveyor is mandatory.

3. Apron conveyors remain as excellent applications under dump hoppers because of their ability to absorb impact. They are, however, inherently "dirty" units and sticky or packing material continually drops from the return run, causing a continual cleanup problem under the apron. All units of this type should be furnished with dribble conveyors to direct drop-off into the main stream of discharged material.

4. Elevator buckets of special design as mentioned in No. 1 above should be furnished with heavier or reinforced lips for digging purposes to accomplish as much automatic cleanout of fallback material in the boot as possible.

5. Elevator casing construction should be carefully scrutinized as to alternate construction with longer intermediates to facilitate erection. Also, support of casing at grade level is advantageous from the standpoint that the full load does not have to be carried full length of casing; thus, all casing sections below grade only support their own weight and can be of lighter construction.

6. Extra large and greater number of access doors should be provided at convenient levels to facilitate inspection and maintenance work on carrying medium and internal machinery.

7. Finally, recognizing buildup of wet muck fines on chain guides, rollers, apron rails and rollers, etc., extra friction factor should be applied in determining horsepower requirements.

What does the future hold for bucket elevators? Based on past experience, present technology, and giving free reign to the most imaginative concepts, a special unit specifically designed for successful mucking operations can be developed. Such a unit could incorporate a feature of the positive discharge unit, in which the chain is knuckled back and buckets are inverted over the discharge for free release. "Super" chains already proven in the laboratory can increase center capability. Intermediate drive concepts, of which workable arrangements already have been designed and working models built, would extend centers almost indefinitely.

Until proven otherwise, the bucket elevator holds a place for consideration. Only the market need be defined to justify research and development on the part of industry, or cooperative efforts of industry and government relationships.

7/27/77

PAPER 12

Early American Mines

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EARLY AMERICAN TUNNELS

BY ROBERT S. MAYO, CIVIL ENGINEER
Presented to the Society of Industrial Archaeology
Wilmington, Del. -- April 20, 1977

Tunneling, for transportation, began in France with the Milpass Tunnel on the Lanquedoc Canal in 1680. Of course, the ancient miners had been driving tunnels in search of minerals since the dawn of history but this Milpas Tunnel was the first tunnel exclusively for transportation. In England in 1760, the Duke of Bridgewater opened a canal from his coal mines to Manchester, 10½ miles away. At the mine, he drove a tunnel into the mountain so that the miners could shovel the coal directly into canal boats. James Brindley, an untutored genious, was his engineer and this whole transportation system was an instant success and very profitable through the years. Within a dozen years the Duke, again with James Brindley, opened up the Grand Trunk Canal, 139 miles in length with five tunnels. There was one major tunnel on this system, the First Harecastle Tunnel, 1½ miles in length. But this tunnel was too small. It was only large enough for one 7-ft wide boat which had to be "legged" through by boatmen laying on their backs. By 1824 a second tunnel was driven parallel to the first one, but it had a towpath through it for horse haulage. This was the beginning of the "Industrial Age" and tunnels became a very important part of the transportation of that era. (Fig. 1)

1. LITTLEBOROUGH SUMMIT TUNNELS. With ample coal and ore, industry boomed.

Our Transportation Era can be said to have begun with the opening of the Erie Canal in 1825. Prior to that date there had been a few canals built in the U.S. and I can mention the Dismal Swamp Canal, the Great Falls Canal just above Washington and the Conowingo Canal on the Susquehanna River above Port Desposit. And, of course, there were numerous plans for canals on any creek or river that, hopefully, might become navigable. The Erie Canal was begun in 1817 and opened in 1825. It was an instant success and soon paid for itself. It was really revolutionary in that it set up a new trade pattern to the Mid-West via the new-fangled steamboats as far as Albany, canal boats 360 miles to Buffalo and lake steamers to Chicago and points along the way. Up to this time Philadelphia had been the largest American seaport with Baltimore close behind. With the opening of the Erie Canal New York became America's largest city, a supremacy it has never lost.

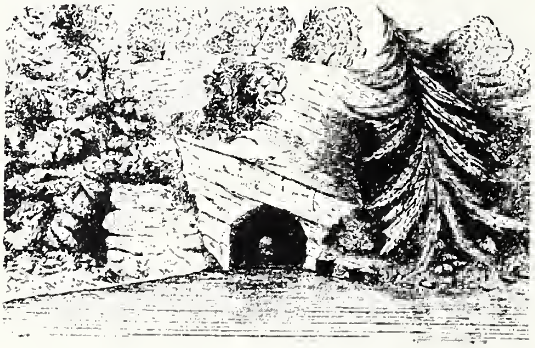
In that period of 1800 to 1825 a number of American engineers had been sent to England and Europe to study canal design and construction and, of course, they saw some of the tunnels which had been built in those countries. I would like to mention a few of these engineers whose names live on in engineering history: Canvass White, Robert Fulton (a local boy), John L. Langdon, Isacc Roberdeau, Solomon Roberts, Charles Ellet, Loammi Baldwin and Horatio Allen. In a further exchange of information, Ross Winans, George Whistler, Johnathan Knight and William McNeill were invited to England to view the famous "Great Locomotive Contest" at Rainhill in 1829. This contest was won by Stephenson's "Rocket". There were a number of foreign engineers who immigrated to this country and took part in canal and tunnel construction. Claude Crozet had served under Napoleon and later built the Blue Ridge Tunnel for the C&O RY. Benjamin Latrobe was an English architect who first worked on improvements to navigation on the lower Susquehanna and then designed the National Capitol in Washington, the Cathedral in Baltimore and the Water Works in Philadelphia. His son, Benjamin Latrobe II, was Chief Engineer of the B&O RR which drove some 44 tunnels, totaling 10 miles, from 1839 to 1871, to connect Baltimore with the Ohio River.

There were several textbooks available to the early American engineers; one was Richard Castle's Essay on Artifical Navigation, 1730. I have not seen this but I do have a copy of Phillips' Inland Navigation, 1805. This is a big book, 598 pages, first published in 1792. Here he describes all the canals in England, Ireland and all of Europe. There is one chapter on "North America" in which he speakes very knowingly of the many canals which were then proposed and later built and he proudly mentions:

> "His Excellency George Washington: twice the savior of his country. After conducting her to liberty, he opened her the way to prosperity by new roads and canals."

The introduction states that Phillips was a "prisoner on parole" in North America from 1780 to 1783. How he became a POW it does not say, I can only assume that he was with the Royal Engineers.

THE TUNNELS



AUBURN TUNNEL - First American tunnel, 1818-1821, 450-ft long. This was on a canal leading to the Schuylkill coal regions. It was through a treacherous red shale and was "daylighted" within a few years.

EARLY AMERICAN TUNNELS

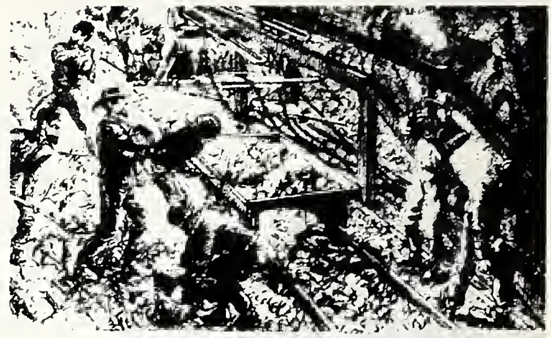
LEBANON TUNNEL - Built 1824-1826 and 600-ft long. This was on the Union Canal connecting the Schuylkill and Susquehanna Rivers. Canvass White was the Chief Engineer. It is now a National Monument and is located just outside of Lebanon, Pa. It is easy to visit.

ALLEGHENY PORTAGE RR - This was the first American railroad tunnel, built 1831-1833 and 900-ft long. Solomon Roberts was Chief Engineer. It stands deserted in the hills high above Johnstown, Pa.

GRANT'S HILL TUNNELS - Located in downtown Pittsburgh. These were uncovered in excavating for a foundation in 1968. The tunnel to the left was for the Pennsylvania Canal, 1830, and the Pennsylvania RR to the right dating from 1865.

PAWPAW TUNNEL - This was on the C&O Canal and was built in 1836 and is 5/8 of a mile in length. It is still there, not far from Pawpaw, W.Va. and is definitely worth a visit. But bring your own flashlight.

HOOSAC TUNNEL - This is the Granddaddy of all American tunnels, 4.7 miles long and it is still in use on the railroad connecting Boston and Albany. The first contractor was Herman Haupt beginning in 1856. Haupt was a West Pointer who had worked on the Summit Tunnel of the PRR. His contract lacked financing and became embroiled in politics so after completing 17% of the job it was terminated in 1861. Haupt became a General in the Civil War and was Lincoln's Chief of Railroads. The contract was completed by the Shanly Brothers, from Canada, on February 9, 1875. It was on this tunnel that the first pneumatic drills and nitro-glycerin were used. With these new tools progress increassed from about 1½-ft per day to 6-ft in each heading, and the cost of drilling reduced by two-thirds. Some 200 men were reported killed on this job, or 42 per mile!



WORK AT THE HEADING IN HOOSAC TUNNEL

In the first 30 years, up to 1850, there were 48 tunnels completed in the U.S. for both canals and railroads. By 1875 Henry Drinker (Tunneling: Explosive Compounds and Rock Drills) listed some 300 tunnels for railroads alone, of these the B&O RR had 55 and the C&O RY 25.

THE TOOLS

All these early tunnels were in rock, sometimes hard, sometimes soft, but all required drilling and blasting. All drilling, up to 1865, was by hand, known as "double-jacking". There were two miners who struck the drill steel with an 8-lb sledge hammer, still known as a "double-jack". There was a helper who held the drill steel, revolving it slightly with every blow. Every so often they would stop while the helper fished out the pulverized rock with a "miner's spoon". The hole was generally 1-in diameter and progress was about a foot per hour. Holes were 3-ft to 4-ft deep. When trimming the walls, holes were drilled by "single-jacking"; here the miner swung a 4-lb hammer in one hand and held the drill steel in the other.

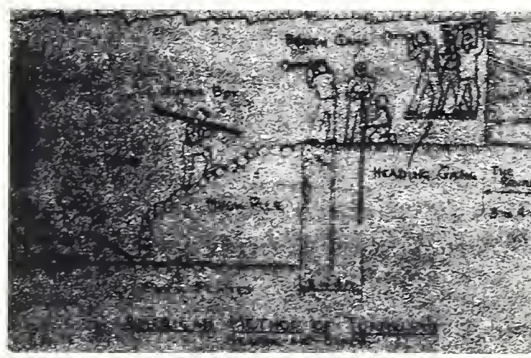
DOUBLE-JACKING IN A CORNISH TIN MINE
(A Rare Photograph)

When the hole was bottomed, the correct amount of black powder was poured

in and the hole was then tamped with clay. But before tamping in the clay a copper "needle", about 3/8 of an inch in diameter was inserted in the hole. This left, when removed, a small hole in which the "squib" or fuse was later inserted. The miners made their own squibs. These were of reeds, straw, goose quills or small paper tubes, filled with black powder. While the Bickford Safety Fuse was patented in 1831, it is doubtful if they were widely used in these early American tunnels.

Once the holes were loaded and the fuses inserted, the heading boss and the lead miners lit them in sequence, the cut holes first, the relievers and then the rib and back holes. The standard warning was "FIRE IN THE HOLE!" I once worked on a job where, on occasion, they used fuse instead of electric caps. There were 24 holes and 24 fuses to be lit and it is an eerie feeling to stand there (my job was to hold the electric lights) and see these fuses smoking away and wonder to yourself if they would get them all lit before it was too late.

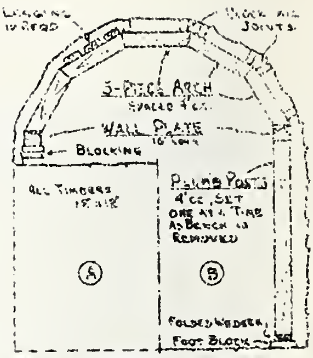
During this period, prior to 1850, the "American Method of Tunneling" was developed, primarily for railroad tunnels. These were driven "heading-and-bench", the bench being about 8-ft wide. Thus, there could be four drill crews working at one time: two at the face and two on the bench. Most important, using this scheme, the muck gang could be working at the same time as the drill gang. Mucking was a slow and tedious operation and overall progress was greatly improved when this could be done without interferring with drilling.



Back in those days a piece of drill steel would only drill about 1-ft so there was a "nipper boy" to carry steel to the face and then carry the dull steel out to the blacksmith to be re-sharpened and re-tempered. Probably one of the greatest improvements in tunnel progress was the introduction of Tungsten Carbide Tipped Drill Steel. Prior to that, even in my time, a piece of drill steel would stay sharp for only 2-ft. With the introduction of the carbide-tipped steel, the miners could go to much longer drill rods and thus a deeper hole because a carbide-tipped drill rod would drill at least 150-ft before it had to be re-sharpened. The "Mole", or Tunnel Boring Machine, depends on carbide faced teeth to bore any kind of rock.

Another important development at this period was the American System of Timbering. This consisted of a five-piece arch, all pieces alike. If the ground needed support, this could be erected in the heading on a "wall plate". All these timbers were 12-in x 12-in. When the bench was taken out the wall plate would support the arch long enough to set the "plumb post" which was wedged tightly in place. The big advantage of this system of timbering was that it could be made wide enough to permit

the permanent concrete lining to be placed when the timbering began to decay. I have been on many jobs were this system of timbering was used, some as late as 1933. Today we use steel H-beams.

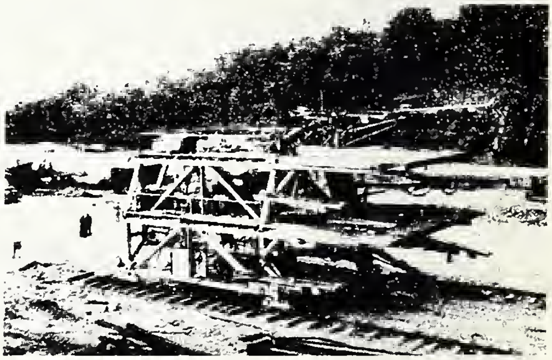


AMERICAN SYSTEM OF TIMBERING

I show an early pneumatic drill. This was probably 1875 but this same type of drill, with some improvements, was used until about 1945. I worked as a "chuck-tender" many years ago on the Moffat Tunnel where we used this type of drill. My job was to change the drill steel every two feet. We started out with a piece of steel 2-ft long and the miner would hand-crank it in and then hand-crank it out. I inserted a 4-footer, a 6-footer and finally an 8-footer. It took four pieces of steel to drill a hole 8-ft deep. Since there were 24 holes in the face there were 96 pieces of steel sent out in the "nipper car" to the blacksmith to be re-sharpened.

All mucking was by hand using either a short D-handled shovel or one with a long handle, still known as a "muck stick." It was desirable to break muck into one-man stones: anything larger than a two-man stone had to be "popped". Haulage was by mine cars running on narrow-gauge tracks or by two-wheeled dump carts carrying one cyd. Mules or horses were the "prime movers." Iron "Slick Plates" were laid on the floor before blasting.

In conclusion and to bring you up-to-date, I show a recent Drill Jumbo for a tunnel on the Pennsylvania Turnpike. This carried eight drills mounted on hydraulically controlled booms. Each drill had a 12-ft feed so that the miners could drill a 12-ft hole which would probably "pull" about 11-ft of tunnel. These new long-feed drills, mounted on hydraulic booms, were only made possible by the development of Tungsten Carbide-Tipped Drill Steel.



MAYO DRILL JUMBO

*   *   *

Robert Mayo is an old-timer in tunneling, his first job was under the Hudson River on the Holland Tunnel. He is co-author of three books: PRACTICAL TUNNEL DRIVING (1941), TUNNELING: THE STATE OF THE ART (1968) and TUNNELING: THE STATE OF THE INDUSTRY (1976). PRACTICAL TUNNEL DRIVING has been reprinted as a paperback and may be obtained from the Author for $15.00 post paid: Box 1413, Lancaster, Pennsylvania 17604.

QUESTIONNAIRE
AND
WORKSHOP FORMAT

Questionnaire and Work Shop Format

The seven divisions of material handling covered by the session speakers were each the subject of a one day work shop. All Conference attendees were assigned to one of those meetings, based on their area of expertise. A roster of those participating in each meeting and the chairmen has been included as an appendix.

The morning of the work shop sessions was generally devoted to a broad ranging review of the state of the art. The afternoon was spent in attempting to identify areas requiring additional research and development, and in defining priorities. A written summary of this thinking was formalized by each group for presentation by the chairman at a final conference meeting the following day.

In an attempt to guide each of the groups into a similar approach a questionnaire was distributed to all participants prior to the workshops, for advance consideration, with the thought that this would be utilized to prepare the work shop conclusions.

These questions were:

1. Based on assessment of the state of the art, list current, near term (5 years) and long term limiting technical problems relative to your technical area.
2. In a broad sense, what is the potential for improvement and the significance of the given improvement for each of the above problems?
3. What is the estimate in dollars and man hours of effort being devoted to defining and solving those problems?
4. Which of these problems will likely be solved with current research and which need added research and development?

5. What effort (dollars and specific programs where possible) is proposed for dealing with those problems which need added research and development efforts?

6. Summarize by stating priorities, scope, cost, and cost/benefit (when possible) of recommended research and development needs. (If you had "X" million dollars for research, where could the money be most effectively spent?)

7. What special government/industry relationships would be desirable to facilitate solutions of the critical problems?

8. If your materials handling system is not limited directly but its supporting sub-system is, list its deficiencies in order of priority. For example, a conveyor belt system may perform adequately except when blocks of rocks hit it. Thus, the muck supply sub-system (crusher, grizzly, etc.) is limiting to the conveyor system.

While the questions undoubtedly helped to focus attention on the areas for future development, some of the groups found it very difficult to fit their thinking into this format. As a consequence, the conclusions of some of the workshops were in broad general terms while at the other extreme, some limited themselves to answering the specific questions provided.

The workshop summaries which follow are those presented to the conference by the chairmen. They are in an outline form because of the relatively limited time available. for this documentation at the workshop. All attendees did receive copies of the summaries at the final meeting at which they were discussed. There has been some minor editing and rearrangement to improve clarity prior to their inclusion in this volume. The summaries are included in the sequence in which they were presented.

Presentation of the seven summaries in the closing morning session severely limited the time available for discussion.

Brief discussion comments have been included after each, merely to indicate the nature of the questions which followed. Unfortunately, they omit some of the more lengthy thoughts expressed due to the difficulty in recording the dialogue.

WORKSHOP SUMMARIES

ELEVATORS

(Work Shop Summary)

1. Based on assessment of the state of the art, list current, near term (5 years) and long term limiting technical problems relative to your technical area.

   Elevators - Short Term

   A. Need buckets that will provide free release of sticky materials.

   B. Need elevator chains with higher allowable working load capability (40,000 to 50,000 pounds) to allow high lifts and higher capacity.

   C. Need capability to handle large size material with highly variable characteristics.

   Elevating Belts - Short Term

   Require increased transverse stiffness of belt to allow increased belt width and/or lump size handled and consequent increased capacity.

   Serpentex Type Belts - Short Term

   Need increased speed to increase capacity.

   Elevators - Long Term

   A. Need to develop intermediate drives to allow elevator lifts greater than 350 feet.

   B. Need to study alternates for chain or the tension member for elevators.

   Elevating Belts - Long Term

   Increased capacity of system by increasing strength of belt of same thickness (higher allowable loading in pounds per inch of width).

   Flexowall Type Belts - Long Term

   Study Vertical handling capability of flexowall belts.

All Systems - Long Term

Double current capacity - The current capacity of these systems is 300 to 400 TPH under the following conditions.

Center to center distances of pullies - up to 250 feet.
Material weighing about 110 lb/ cubic foot.
Maximum of 8 inch lump - no more than 15% of volume to be maximum lumps.
Design based on a single job life.

2. In a broad sense, what is the potential for improvement and the significance of the given improvement for each of the above problems?

Elevators:

A. Buckets freely releasing sticky material - chance for acceptable solution for rock very good but poor for clay.

B. Higher allowable load capability for elevator chains - chance for achieving is excellent.

C. Need to handle large lump, varied materials - chance for achieving is fair.

Elevating Belts:

Greater transverse stiffness of belts - chance of achieving is very good.

Serpentix Type Belt:

Increase speed of serpentex belts - probable.

Elevators:

A. Intermediate drives for chain elevators - chance of achieving is good.

B. Alternates to chain - will require research and application development.

Elevating Belts:

Increased strength of belt same thickness - probability of achieving very good.

Flexowall Type Belts:

Vertical handling capability flexowall belt - chance of achieving is good.

All Systems:

Double current capacity on all elevating systems - chance of achieving is good.

3. What is the estimate in dollars and man hours of effort being devoted to defining and solving those problems?

Elevators:

None that is directed solely to solution of these problems.

Elevating Belts:

Indirectly being solved or understanding increased by work on other applications - this indirect effort evalutated as:

Approximately 10 man years/year.
Total $300,000/year.

Serpentix Type Belts:

Most work is being direct towards a specific application outside tunnel industry.

4. Which of these problems will likely be solved with current research and which need added research and development?

Short term problems listed will probably all be acceptably solved with current research with the exception of handling sticky materials in bucket elevators.

Most of the long term problems could become short term with good chance of acceptable solution by current research if there is a demonstrated market.

Other long term problems will require additional research and development.

5. What effort (dollars and specific programs where possible) is proposed for dealing with those problems which need added research and development efforts?

Intermediate Drive - a program of $500,000.00

Project to Develop Transverse Belt Stiffness (Elevating belts) - a program of $150,000.00

Substitution For Chains - an ongoing program.

Vertical Conveying With Flexowall Type Conveyors - a program of $250,000.00

6. Summarize by stating priorities, scope, cost, and cost/benefit (when possible) of recommenced research and development needs. (If you had "X" million dollars for research, where could the money be most effectively spent?

   The overall priority sequence is as follows:

   Elevators:

   Handle sticky material.

   Intermediate chain drive.

   Investigate related technologies in the U.S. and abroad.

   Elevating Belts:

   Stiffness development.

   Vertical conveying with flexowall type conveyors.

7. What special government/industry relationships should be desirable to facilitate solutions of the critical problems?

   Provide funding for dual hoisting - elevating in several construction projects wherein manufacturers and contractors could participate without being penalized.

8. If your materials handling system is not limited directly but its supporting sub-system is, list its deficiencies in order of priority,. For example, a conveyor belt system may perform adequately except when blocks of rocks hit it. Thus, the muck supply sub-system (crusher, grizzly, etc.) is limiting to the conveyor system.

   Muck size - limits all elevating systems.

   A continuous conveying system must be fed a sized material at a rate not exceeding design capacity. Unless sizing techniques are used this will prohibit their application by shoot and drill operators. Low profile crushing equipment should be investigated.

In general there has been a reluctance among tunnel contractors to utilize bucket elevators or elevating belt conveyors for the removal of tunnel muck. Until recently, the traditional method of muck removal has been by crane or hoist. Two tunnel projects now under construction are using bucket elevators for the first time in the industry.

Bucket elevators have been used in many industrial applications. The construction industry poses a challenge in that the material is not always a constant product. Long tunnels intersect a variety of geological formations with varying properties including varying moisture content. The use of tunnel boring machines produces a more uniform end product which is easily adapted to continuous handling machinery.

Proper sizing of material is the prime factor and materials from drill and blast operations could also be removed by these systems if the material could be sized correctly and efficiently.

Development of the bucket elevator for mucking has been limited by the market. If the market were expanded, many of the present day problems associated with the use for tunneling would be solved by in-house development. Industry is reluctant to spend money for research in limited applications.

Present day technology offers capacity of 300 to 400 tons per hour for lifts to 250 feet. Technology is available to increase these capabilities and lifts given the proper incentive.

Discharging of sticky material is the principal problem and has a questionable chance of being solved for clays but a good chance for rock in the short term. This problem is less severe in belt elevating systems.

All projects require careful investigation as to whether substantially standard systems can be used.

Belt systems are available in slight variations utilizing rubber belts of varying configurations. Flexowall, Beltavators and others use different configurations to accomplish the same function as bucket elevators. Sizing of the material is also required.

Discussion

Emphasis was placed on the need to improve the capability of systems to handle a broader mix of materials, and in particular, to cope with the severe problems related to sticky materials.

Elevators have had few applications in the tunneling industry, hence the market is considered small and few industrial companies are allocating dollars to R&D for design improvement.

Flexowall type conveyors are utilized in a variety of applications overseas at angles up to about 45°. When a cover belt is added, units have been operated up to 90° (vertical).

HOISTING

(Work Shop Summary)

The equipment and application technology presently availalbe are adequate for present day mining and construction shaft hoisting. There appears to be a problem of distribution of this knowledge especially in the area of shallow shaft hoisting.

We therefore suggest that a survey of the state of the art of the problems of design, selecting and applications of materials handling in shallow(<500') shafts be conducted under the sponsorship of the DOT. This study would have an estimated cost of $250,000.00. To the best of our knowledge there is no research money being spent in this area at present.

The areas enumerated below could be addressed in the study:

1. Design Criteria

    Capacity
    Depth
    Material (muck,equipment, personnel)
    Shaft configuration

2. Survey of Existing Methods and Equipment

    Hoists
    Cranes
    Loading/unloading equipment
    Conveyances
    Furnishings
    Headframes
    Communications
    Portability

3. Integration of Components into the Hoisting System

    Safety
    Economics (capital and operating costs)
    Maning and Productivity

4. Review of Current and Pending Legislation and Its Impact

    State
    Federal

5. Future Trends

Recommendations for Future Research

Discussion

Twenty different methods are currently employed for loading ships in mining operations. While there is room for improvement, there was a general feeling that the present equipment is adequate for depths under 500 feet. Hoists are available from manufacturers within 6 months for the smaller sizes, if the requirements for special engineering are not excessive.

A problem was encountered with over heating of the hydraulic oil in hoists on a New York water tunnel project. It was felt that with improved understanding of the application requirements this problem would not be critical in the future. The largest hydraulic hoists at this time are about 400 horsepower frequently using low speed-high torque motor designs. Overall hydraulic system efficiency was believed to range between 75 and 85% with costs about 75% of an equivalent electrical unit.

Hoists are frequently moved from one operation to another so that units in service may have been on 6 or 8 prior jobs.

The Keynote speaker suggested that line speeds of 5000 fpm might be available in the future. This was believed to be overly optimistic with current line speeds approaching 3500 fpm.

PNEUMATIC PIPELINE

(Work Shop Summary)

1. Based on assessment of the state of the art, list current, near term (5 years) and long term limiting technical problems relative to your technical area.

   The current problems associated with pneumatic conveying of tunnel muck are:

   distance
   abrasive wear
   integration with present design of tunnel boring machines
   power consumption
   capacity
   undirectional material transport capability
   limited experience in clay and certain other materials.

   The near term problems relate to distance conveying, abrasive wear, power consumption, and the integration with design of tunnel boring machines.

   In the long term, with the increase in productivity in tunnel boring machines, the capacity of pneumatic conveying systems will have to be increased. The basic problem of power consumption and unidirectional movement will remain.

2. In a broad sense, what is the potential for improvement and the significance of the given improvement for each of the above problems?

   The potential for improvement in each of the above quoted problems will be as follows.

   A. Distance. In the long term high pressure closed loop pneumatic systems will enable distances of five miles and more to be feasible.

   B. Abrasive wear. Continued improvement in metalurgy, design of components and maintenance will result in more acceptable running costs.

   C. Integration with tunnel boring machines. To date this approach has been taken on a limited scale by adding the pneumatic systems behind the boring machine. Advantages to be gained in completely

integrating the feeder within the tunneling machine itself, includes utilization of machine hydraulics to power the feeder, less space required, recirculation of oversize to the cutting head and one operator in place of two.

D. Power consumption. No improvement. It can be anticipated that high power consumption in a pneumatic conveying system is inherent.

E. Capacity. Existing equipment is capable of handling 200 tons per hour, which should be sufficient for the immediate future. As tunnel boring machine capacity increases, corresponding throughputs of pneumatic systems could be increased to 300-400 tons per hour.

F. Unidirectional. The pneumatic pipeline can only convey muck out of a tunnel. The transportation of materials, spare parts and men must be accomplished by some other transportation system.

G. Clays. The problem of conveying clays and other sticky materials can be solved with more experience. Past-installations have shown that in sticky materials the tunnel boring machine has encountered serious operational problems prior to failure of the pneumatic conveying system.

3. What is the estimate in dollars and man hours of effort being devoted to defining and solving those problems?

For calendar 1977 we estimate that the effort being devoted to the defining and solving of the foregoing problems amounts to approximately $320,000.00 divided appoximately equally between industry and government supported efforts. We estimate that about 5,000 man-hours are involved.

4. Which of these problems will likely be solved with current research and which need added research and development?

Current efforts will probably solve the following problems.

A. Integration of the tunnel boring machine with the components of the pneumatic pipeline system.

B. Increase pneumatic pipeline system capacities to meet needs in future years.

The other problems, for which we feel there are solutions, will require added research and development.

5. What effort (dollars and specific programs where possible) is proposed for dealing with those problems which need added research and development efforts?

Two research programs are proposed to deal with two problems for which no research or development program currently exists.

Research and prototype development for a high air density pneumatic system to operate in a closed loop. The pressure drop thru the system would be nominally 10 PSI. High pressure air will provide a more dense medium than is achieved with current systems. This sytem could transport muck to distances in excess of the 3000 feet currently achievable, and with lower air velocity and less pipe wear. Such a system will find uses in a wide variety of applications in industry.

Estimated Cost - $1,000,000

A research program to investigate abrasive wear of rock on pneumatic system components. It is proposed that a pneumatic system be installed in an active quarry where the product is fresh rock three inches or less in size. Measurements of wear on a variety of abrasive resistant materials would be recorded. The equipment would then be moved to another quarry with a different type of rock and similar tests run. The purpose of these tests will be to determine the optimum abrasive resistant materials for a variety of rock types.

Estimated cost - $1,000,000

6. Summarize by stating priorites, scope, cost and cost/benefit (when possible) of recommended research and development needs. (If you had "x" million dollars for research, where could the money be most effectively spent?)

Equal priority is suggested for the two research areas proposed above.

7. What special government/industry relationships would be desirable to facilitate solutions of the critical problems?

We feel that present relationships form a basis for a start on efforts to solve the problems cited, but a substantial strengthening is required by a heavier government and industry committment to funding.

8. If your materials handling system is not limited directly but its supporting sub-system is, list its deficiences in order of priority. For example, a conveyor belt system may perform adequately except when blocks or rocks hit it. Thus, the muck supply sub-system (crusher, grizzly, etc.) is limiting to the conveyor system.

   A crusher for pre-sizing muck is limiting to the pneumatic pipeline system for tunneling applications.

Discussion

Current pipe being used comes from Germany. It is rolled and welded, then the inside surface is flame hardened to 650-750 BHN. Basalt pipe has proven to be too heavy and brittle to handle and the manufacturer will not recommend elbow installations for coarse solids.

Wear in feeders is at an acceptable level but high wear is being experienced in elbows. Dirt back elbows (double pipe design) appears to offer some potential.

Air velocity must be kept as low as practical. Currently the velocity of the feeder is maintained at about 120 feet/second and increases as it passes thru the system.

A 300-400 ton/hr system, 3000 feet long, would require an estimated 1200 horsepower but could vary significantly dependent on the system configuration.

SLURRY PIPELINE

(Work Shop Summary)

Based on the experience of the panel, slurry pipelines can provide very low unit transportation costs. The method is not widely used in the tunneling industry because of problems that have only recently been solved (or can be solved in the near future). At this time the active market is very narrow, limited to tunneling coal, sands, gravels and weak sandstone. However, with the recent development of better feeders, pumps, pipe and separators for other applications, the market is growing. Further development of the engineering data and equipment (listed later in this report) will permit utilization of hydraulic transportation for tunnel construction and increased potential market penetration. To justify research and development by the private and public sectors this potential market must be defined. To carry out this market study the relationship between cost and other parameters, such as geology, geometry, excavation method, must be known as well as the information on tunnels planned for the future. The following three tasks are given the highest priority and should be funded by the public sector as soon as possible and given wide distribution throughout the industry.

1. Definition of Area of Applicability of Hydraulic Transportation in Tunneling.

2. Assessment of Applicability of Method of Excavation with Hydraulic Transportation.

3. Assessment of Market for Hydraulic Transport in Tunneling.

These would be paper studies incorporating input from the entire industry. They should be performed by one firm, using sub-consultants, to insure continuity and speed.

The following problems identified by the panel are considered real and important. They have been rated as to time frame, potential for solution, significance, adequacy of current funding, priority and relative support needed for solution. These and other problems would be reviewed after the first three tasks are complete. This review could be incorporated into the market study.

A1. Hydraulic transport becomes simpler and cheaper as average particle size decreases (above colloidal). Tunnel sites should be assessed on the basis of the feasibility of producing, or of reducing, tunnel muck to hydraulic

transport size.

A2. Concurrently, excavation methods for sites considered in (1) must be considered for effectiveness in making bore and the resulting average muck size. (For example, a mole is likely to produce a more suitable muck than drill and shoot.)

B1. Samples of muck are required to define slurry flow parameters. Drilling cores are required to define flow properties versus slurry preparation possibilities. The need for uniformity in the geological formation may be more important for slurry transport.

B2. Pumping head requirements depend on particle size distribution, density, shape and concentration. This dependency is not adequately defined for engineering application analysis.

B3. Particles deposit and stop flow when the line velocity drops below a certain point depending on (B-2) above. This requires better definition for confidence in operation.

B4. Polymers and colloids added to water reduce power required per ton of solids moved to some extent. Economics of this approach (not good to this date) requires definition or resolution.

B5. As a slurry approaches zero solid concentration, power (and hardware required) per ton transported become infinite. Similarly, as concentration increases fluidity is lost. The optimum concentration for least power - least hardware, requires definition.

B6. Plugging is defined as a loss of throughput. Causes (including B-3) and cures need definition.

B7. Muck must be adequately sized for easy feeding into the water stream and for easy separation from the water at the disposal point. Water must be recycled or disposed of if the tunnel generates water.

B8. Solid suspensions cause wear, attrition and sometimes corrosiveness. Means to reduce or eliminate these are desirable for reduced cost.

B9. Efficient operation of a slurry transport system requires on-line measurements. Instruments for slurry measurements with satisfactory reliability and life in tunnel driving environments are not available and must be developed.

C1. Feeders for introducing solids into a pipeline require development to provide greater flexibility, reliability and capacity.

C2. Pumps are considered adequate. However, better efficiency, less wear, at reasonable first costs, are desired for reduced operating cost.

C3. Better equipment is required to move muck from the excavation point to the feeder.

C4. Crushers that require less head room, but ideally weigh less and occupy less volume are required for tunnels when secondary breakage is needed.

C5. Materials which reduce overall costs by extending equipment life or which cost less for equivalent life are required.

C6. More complete separation (drier solids, clearer liquid) and lower purchase and operating (energy) costs for separation equipment are needed.

D1. Future economics for slurry transport depends on improved equipment being available and the wider distribution of information on its economics. Manufacturers will provide this if the market size (and profit prospects) warrants their efforts. An evaluation of the market is required to establish its size and growth potential to stimulate development and broaden the number of suppliers.

D2. Contracting procedures must be reviewed to insure that latitude in method is possible and that risks and rewards in performance can be shared.

D3. A major objection to hydraulic transportation has been the need for a second transport system for men, equipment, lining and temporary support materials. The use of grouts and shotcretes is extensively used overseas and is increasingly used here. Its extension to a wider range of conditions and the development of long distance pumping capabilitites would complement hydraulic transportation. Pumpable rapid setting concrete for temporary support behind soft ground shields would be valuable.

Hydraulic Haulage Applicability to Tunnel and Shafts
Limiting Technical Problems

	Short or Long Term		Potential for Improvement					
			Potential		Significance		R&D	
	S	L	Good	Poor	High	Low	Current	Needed
A. Application								
1. Definition of Area of Applicability of Hydraulic Tranport	*	*	8*	0*	8*	0*	0*	8*
2. Assessment of Applicability of Method of Excavation to Hydraulic Transport	*	*	8	0	8	0	0	8
B. Lack of Engineering Design Data								
1. Pre-excavation Site Investigation for Muck Properties	*	*	4	4	8	0	0	8
2. Particle Size Distribution	*	*	6	2	8	0	8	0
3. Minimum Transport Velocity	*	*	7	1	4	4	8	0
4. Use of Carrier Media	*	*	4	4	1	7	4	4
5. Maximum Concentration	*	*	8	0	8	0	8	0
6. Plugging: Causes and Cures	*	*	5	3	3	5	8	0
7. Preparation, Separation,and Disposal	*	*	0	8	8	0	0	8
8. Wear, Attrition and Corrosion	*	*	0	8	0	8	0	8
9. Instrumentation	*	*	8	0	8	0	8	0
C. Lack of Good Equipment Specifically Desgined for Tunneling								
1. Feeders (Solids Injectors)	*	*	8	0	8	0	8	0
2. Pumps	6	2	0	8	1	7	8	0
3. Flexible Haulage Equipment	*	*	8	0	8	0	0	8
4. Crushers	*	*	0	8	8	0	0	8
5. Wear Resistance Material	*	*	0	8	0	8	8	0
6. Separation	*	*	4	4	7	1	0	8
D. Economics								
1. Assessment of Market for Hydraulic Transport in Tunneling	*	*	8	0	8	0	0	8
2. Contracting Procedures Redefinition	*	*	8	0	8	0	0	8
3. Development of Pumpable Support Materials	*	*	8	0	8	0	4	4

Numbers indicate individual opinions of participants (8 attendees)

* Members considered these topics to be both short and long term problems.

Proposed Distribution of R&D Funds

PRIORITY	ITEM	Requiring R&D	* RELATIVE COST	GOV'T/INDUSTRY PARTICIPATION	
				G	I
1.	A1	Definition of areas of applicability of hydraulic transport	2	100	0
2	A2	Assessment of applicability of method of excavation to hydraulic transport	2	100	0
3	D1	Assessment of market for hydraulic transport in tunneling	1	100	0
4	C6	Separation equipment	20	25	75
5	B7	Engineering data for preparation, separation and disposal	25	80	20
6	B1	Engineering data for pre-excavation site investigation for muck properties.	11	50	50
7	C4	Crushing equipment	10	50	50
8	C3	Flexible haulage equipment	9	25	75
9	D3	Development of pumpable support materials	10	25	75
10	D2	Contracting procedures redefinition	1	50	50
11	B8	Engineering data on wear, attrition and corrosion	6	10	90
12	B4	Engineering data on usage of carrier media	3	20	80

*Indicates best estimate of cost split assuming modest total level of support (% of total expenditure)

Discussion

The discussion centered on the relative cost of slurry transport systems compared with other systems such as rail. While it was generally believed that slurry unit costs were low no specific information was presented in sufficient detail to permit conclusions.

BELT CONVEYORS

(Work Shop Summary)

1. Based on assessment of the state of the art, list current, near term (5 years) and long term limiting technical prob lems relative to your technical area.

    Steep angle conveyors (up to 90^{o} slopes)
    Gradual curve conveyors (200 ft. radius minimum-horizontal)
    Flexible belts (15 ft. radius minimum)
    Extensible belt systems
    In line crushing
    - a. continuous mining
    - b. cyclic mining

2. In a broad sense, what is the potential for improvement and the significance of the given improvement for each of the above problems?

    I. Steep Angle Conveyors

    A. Drag Chains

    1. Low cost
    2. Applicable 0 to 45^{o} slopes
    3. Low capacity
    4. High noise level
    5. High wear in muck handling
    6. High power consumption
        Low potential for significant further improvement

    B. Specialty Belts (Cleated and/or Sidewall configurations)

    1. High cost
    2. Applicable 0 to 90^{o} slopes. Limited experience with cover belts required for steeper angles.
    3. High capacity
    4. Low noise level
    5. Wear equivalent to standard belts.
    6. Potential problems with sticky materials
    7. Few manufacturers
        High potential for improvement

    C. Spiral Conveyors

    1. Undeveloped
    2. Possibly high cost.
        Further study required to provide better insight into potential for development.

II. Gradual Horizontal Curves

1. Undeveloped
2. Broad applications to installations
   a. Underground-tunnels & mining
   b. Above ground-strip mines & quarries
3. Capable of being shifted sideways under load

   High potential for improvement

III. Flexible Belts

1. Present units experimental
2. Have only been used in coal, no experience in rock
3. Presently a fixed length conveyor
4. Eliminates transfer points
5. Eliminates multiple drives of a "cascade" system
6. High cost
7. Currently - monorail suspension appears superior in adapting to curves and undulations
8. Particularly adaptable to coal room and pillar mining
9. Possible use as connecting conveyor to a tunnel boring machine

   Low potential for improvement

IV. Extensibility

1. System must be capable of accepting material from excavator during all scheduled operating hours
2. Satisfactory systems are available for up to 500 ft. extension.
3. Improvements are possible in the resetting and main line extension operations

   Intermediate potential for improvement

V. In Line Crushing

1. Required if max feed is excessive in size
2. Optimize conveyor life
3. Permits smaller and more economical conveyor systems
4. Essential when conventional drill and blast excavating procedures are employed
5. Limited experience with feeder/breaker in rock
6. High volume thruputs required
7. Large reduction capability - 36" to 8"
8. Low head-room
9. Low cost per ton
10. Portable and moveable

    High potential for improvement

3. Which of these problems will likely be solved with current research and which need added research and development?

   Steep angle conveyors - added research and development required

Gradual curve conveyors - added research and development required
Flexible belts - application and test support is required
Extensibility - application and test support required
In line crushing - added reasearch and development required

4. What effort (dollars and specific programs where possible) is proposed for dealing with those problems which need added research and development efforts?

Steep angle conveyors	5 million
Gradual curved conveyors	10 million
Flexible belts	2 million
Extensibility	2 million
In-Line crushing	8 million

(Cost estimates assume R&D plus bringing the product into production)

5. Summarize by stating priorities, scope, cost, and cost/benefit (when possible) of recommended research and development needs. (If you had "X" million dollars for research, where could money be most effectively spent?)

In answer to this question, we have divided the priority ratings between underground construction and others.

	Priority Rating	
	Underground	Other
Steep Angle Conveyor	1	2
Gradual Curve Conveyors	2	3
Flexible Belts	5	5
Extensibility	4	4
In-Line Crushing	3	1

6. What special government/industry relationships would be desirable to facilitate solutions to the critical problems?

Proprietary rights for developer
Safeguard opportunity for profit for developer
Profit protection for contractors using experimental equipment
While in experimental development stage - product liability protection
Reduced paperwork - submissions and contract administration
Progressive payments - made promptly

7. If your materials handling system is not limited directly but its supporting sub-systen is, list its deficiencies in order of priority. For example, a conveyor belt system may perform adequately except when blocks of rocks hit it.

Thus, the muck supply sub-system (crusher, grizzly, etc.) is limiting to conveyor system.

In-line crushing
Grizzly/Feeders
Transfer equipment from primary haul unit (in cyclic operations) to feeder.

Discussion

Belt conveyors are often overlooked for the tunnel main haulage system, possibly due to their unidirectional haulage characteristics. Wet tunnels pose problems but the availability of such systems has in general been excellent. An underground mine application was described with 30,000 feet of conveyor, in 4 complete systems, which has been handling 2-1/2 million tons per year with 1-1/2% downtime. Good maintenance with continued inspection are essential with concentration on the transfer points.

The use of cascading conveyors to provide extensibility multiplies the number of transfer points and independent conveyor systems tending to reduce overall availability.

The application of conveyor systems would be broadened if good in-line muck crushing equipment were available with acceptable operating costs. There is presently only limited operating experience available for detailed evaluation of this approach. Stamler Company feeder breakers have been applied in rock at the White Pine Mine.

RAIL HAULAGE

(Work Shop Summary)

1. Based on assessment of the state of the art, list current, near term (5 years) and long term limiting technical problems relative to your technical area.

There are no limiting technical problems for rail haulage for the foreseeable future, to achieve 6" per minute penetration (800 tph), on grades of 5% or less, provided diesel locomotives are used.

Assumed Basic Parameters:

20 ft. diameter, circular, mole-excavated tunnel, 20,000 ft. long.
Access by single shaft
Maximum 5% adverse grade by 1,000 ft. long
Rolling stock 6 ft. maximum width

(Instantaneous Rates)	Today	5 Years	Long Term
Advance ("/min)	4	5	6
Production TPH	500	650	800

Prohibition of diesel power would greatly increase the cost of tunneling. It would make the cost of underground mining prohibitively expensive and would greatly increase the frequency and severity of accidents.

Live axle vs. dead axle muck cars: Large railroad systems use live axle cars. Construction and mining projects almost always use dead axle muck cars. Tradition appears to be the only reason for using dead axles. This apparently stemmed from the very short radius curves that were used 100 years ago. Dead axles (live wheels) were required to negotiate these curves without skidding the inner wheel. There was no agreement within the panel on whether live axles should be used on muck cars. Possible advantages are less rolling resistance, less flange wear, and fewer derailments. Possible disadvantages are more resistance on curves and high cost. The answer to this involves a complete understanding of the dynamic action of the wheel - rail interface. Location of this expertise was unknown to the panel members. Several members of the panel plan to investigate this, and, it would appear that live axels will be tried on a construction project in the near future.

2. In a broad sense, what is the potential for improvement and the significance of the given improvement for each of the above problems?

For rail haul on greater than 5% grades:

Power alternates
1. cable assist
2. cog rail drive
3. power muck cars
4. trolly assist

Brakes on all cars
Derailers for runaways
Additional ventilation for diesel exhaust fumes

3. What is the estimate in dollars and man hours of effort being devoted to defining and solving those problems?

The only related research is on cog drive locos and self-adjusting brakes in England. Dollars unknown.

4. Which of these problems will likely be solved with current research and which need added research and development?

All these problems will be solved with normal equipment development as the need arises.

5. What effort (dollars and specific programs where possible) is proposed for dealing with those problems which need added research and development efforts?

For proper ventilation of diesel exhaust fumes, an air quality performance specification (e.g. 50 ppm CO and 5 ppm NO_2) is required rather than an arbitrarily specified CFM for a specific engine (e.g. 50,000 CFM for a Cat 1963 TA).

Effort required:

1. Gather information to justify change		2 man-years
2. Work shop to present finding		1 man-year
	Total - Time	3 man-years
	Dollars	$300,000.00

6. Summarize by stating priorities, scope, cost and benefit/cost (when possible) of recommended research and development needs. (If you had "X" million dollars for research, where could the money be most effectively spent?)

Air Quality Performance Specification

Cost	$300,000.00
Benefit/Cost ratio	7:1 (first year)

7. What special government/industry relationships would be desirable to facilitate solutions of the critical problems?

   Establish liaison between industry and government representation to discuss regulations and regulatory needs in the concept stage to:

      Improve the understanding of the nature of regulatory impacts and establish more realistic benefit/cost relationships.

      Permit industry to more effectively contribute technical input.

      Balanced interests to better serve the general public.

8. If your materials handling system is not limited directly but its supporting sub-system is, list its deficiencies in order of priority. For example, a conveyor belt system may perform adequately except when blocks of rocks hit it. Thus, the muck supply sub-system (crusher, grizzly, etc.) is limiting to the conveyor system.

   Rail haulage requires no muck preparation and no supporting sub-system to transport men and materials in the tunnel.

   The main delay to the underground excavation system, today, is the installation of the initial ground support. The rail panel felt that government research funds should be concentrated in this area.

Discussion

Cog wheel development underway in England is of interest. A compact locomotive with over 1000 horsepower could pull a muck train up a 30% slope.

An American Society of Mechanical Engineers committee has been working on the wheel-rail interface problem for the past 20 years.

There was a comment from one participant regarding the problem of securing government support for projects that were not related to exotic new concepts. For projects such as those related to rail haulage, it was essential that industry focus upon identifying development areas with the greatest payoff potential and provide good back-up information for funding decisions.

RUBBER TIRE HAULAGE

(Work Shop Summary)

The areas of concern for rubber tire haulage vehicles fall into three major categories:

I. Applications on job
   A. Pave roads
   B. Engineering design
   C. Maintenance/service

II. Machine Design
   A. Improve existing machines
   B. Power Source Packages
   C. Totally new concepts

III. Health and Safety Aspects
   A. Governmental regulations
   B. Control of operational influences

The dollar value of the current research in the above listed categories is unknown. Priorities for each category (assigned a percentage value) however have been developed as a suggested guide for the allocation of future expenditures.

I. Applications		
A. Pave roads		3%
B. Engineering design		2%
C. Mainenance/service		10%
	Total	15%
II. Machine Design		
A. Improve existing		40%
B. Power source		20%
C. New concepts		15%
	Total	75%
III. Health and Safety		
A. Government regulation		3%
B. Control operational influence		7%
	Total	10%
	Grand Total	100%

It was generally concluded that the current level of research (whatever its dollar value) has not been adequate to keep pace with increased costs generated by new regulations, inflation, etc.

There are no technical limitations in any of the categories. Increased effort would continue to result in improvement in all areas. In other words, the potential for improvement is fair to good in all categories.

In all cases the government/industry relationship was recommended to be one of information exhange and dissemination only. The problems themselves will be solved by private industry working to meet realistic regulations with a realistic time schedule.

With the exception of ventilation, no supporting sub-system is severely limiting rubber tired materials handling system.

A more detailed analysis of each category follows:

IA. Haul Roads
1. Stabilization of soft ground haul roads
    a. Chemical
    b. Gravel
    c. Concrete
2. Portable or reuseable base
    a. Concrete
    b. Steel

B. Engineering Design - Permanent Works
1. Consideration of construction practices
2. Equipment application in civil construction design

C. Maintenance/Service
1. Adverse conditions underground lead to higher down time than surface operations due to
    a. Work place conditions
    b. Less procedural arrangements to take care of maintenance
2. Educational requirements at all levels a necessity.

IIA Improve existing machine design
1. Versatility
2. Mobility
3. Modular construction
4. Payload/deadload ratio
5. System-
    Brakes
    Hydraulics
    Electrical
    Air
6. Tires
7. Maintainability
8. Capacity

B. Power System
   1. Improve Diesel
      a. Fuel
      b. Combustion
      c. Scrubbers
      d. Coolers
   2. Improve Electrical
      a. Power transmission to unit
      b. Small-high energy batteries
   3. Develop alternative power sources

C. New Concepts
   1. Combined haulage systems
   2. Automation
   3. Other-to be defined
   4. Rubber inline mucker

IIIA. Health and Safety
   1. Regulations should not exceed best available and most cost effective technologies.
      a. Regulations to specify results and not methods
         Reasons: Presently no advantage to companies that do a good job in research and development.
      b. Uniformity of regulations and enforcement by all agencies with special consideration for the differences between underground construction, metal mining and coal mining.

B. Control of Operating Influences
   1. Ventilation
   2. Noise
   3. Dust
   4. Illumination
   5. Emissions
   6. Braking
   7. Fire Suppression
   8. Rops and Fops (systems)
   9. Visibility
   10. FRF Hydraulic fluids
   11. Sensor systems and controls

Research and development programs are addressing themselves to the problems of the working place. The result of implementation in some instances have proven sucessful. Achieving further results will be more difficult and will take longer.

The objectives and goals of the AMC Manufacturer Diesel Sub Committee to further the use of diesel equipment in coal mining and other underground applications are very noteworthy.

Discussion

The discussion related primarily to the problems associated with diesel emmissions underground and the advantages of a diesel shuttle car. Some diesel shuttle cars are operating underground but none are in coal.

Good maintenance remains essential to equipment performance. Scrubbers in particular were mentioned as needing careful maintenance. Tires fortunately have improved significantly over the years and are now less serious problems.

CLOSING REMARKS

J.W. Martin
Workshop Coordinator

Closing Remarks

(J.W. Martin-Coordinator)

The workshop teams are to be complimented for their accomplishments on a very tough assignment. It is extremely difficult in one day to identify problem areas and the short comings in the state of the art in such complex fields and then turn around and try to project them concisely, with priorities, into a broad user-industry-government development effort. The progress made, attests to the capabilities of the participants.

The conclusions reached varied widely with respect to the apparent future opportunities for development because we are dealing with technical areas which are at different points in their life cycle. Hoist and rail systems have been used and progressively refined for decades and might be viewed as mature products with relatively low potential for major innovations. Elevators, trucks and conveyors are of a more recent generation and while in broad usage still offer the opportunity for some breakthroughs. Pneumatic and slurry pipelines while old in concept have not achieved extensive usage and require further research to reach their full development.

In the time available and with the data on hand it was difficult to present specific cost data. This aspect was further clouded by the lack of any agreement as to what costs were to be considered. Some of the estimates presented relate only to the research required while others represent the cost to put a new product into production. Many of the participants were actively engaged in related research and development, and were not at liberty to disclose their current experience.

Adaptation and expanded use of all these material handling systems in underground tunneling requires equipment modifications and development. This is not occurring as rapidly as desired because few of the major suppliers appear to recognize or understand this potential market.

In the discussions, we were constantly switching back and forth between present and future practices. Much of the present tunneling is by "conventional methods", while the future is generally associated with "tunnel boring machines". Basically, this is saying our objective is a transition from cyclic to continuous operations. As we strive to approach the concept of continuous haulage, the systems input must be more controlled. The next step requires further consideration of feeder-breakers and other devices to control size and reduce surging.

Finally, it is of interest to note briefly, the varied reactions to the question of what part government should play. Again the suggestions seem to tie in with the level of the particular technology. Those associated with the older systems desire an increased opportunity for dialogue on the expanding government regulations. The younger systems require better information exchange so that everyone benefits from current research and improved business relations in the conducting of government sponsored work. The newer, less proven systems seem to need government funding to bring them to a point where they could become an effective industrial market and stand on their own.

APPENDIX

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